Developing a framework and understanding the key influencing factors for the implementation of the Internet of Things (IoT) in the UK Construction Sector.

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PhD Thesis **2024**

Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

Abbreviation	Acronyms
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
CC	Cloud Computing
CV	Computer Vision
GDP	Gross Domestic Product
GIS	Geographical Information System
IoT	Internet of Things
KIF	Key Influencing Factor
KPI	Key Performance Indicator
MC	Mobile Computing
MCC	Mobile Cloud Computing
PMS	Performance Measurement System
RFID	Radio Frequency Identification
SME	Small and Medium Entreprises
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
WSN	Wireless Sensor Network

Acknowledgements

I would like to express gratitude to those who have supported and guided them throughout their research journey. In my case, I would like to thank my supervisor, Professor Zeeshan Aziz for their invaluable guidance, expertise, and encouragement throughout the entire process. Their feedback and advice have been instrumental in shaping my research and helping me navigate the challenges that come with pursuing a PhD.

I would also like to express my deepest gratitude to my parents for their unwavering support, love, and belief in me. Their sacrifices and encouragement have been a constant source of motivation for me, and I am forever grateful for everything they have done to help me reach this milestone.

Last but certainly not least, I want to thank my wife, my lovely friend, Dr Parisa Meysami for her patience, understanding, and unwavering support throughout this journey. Her love and encouragement have been a constant source of strength for me, and I am truly blessed to have her by my side.

Dedication

I would like to dedicate my PhD thesis to my parents, whose unwavering support and encouragement have been the foundation of my academic journey. To my wife, Dr Parisa Meysami, who has stood by me through late nights of research and writing, always believing in me and pushing me to reach my full potential. And to my son, my little one, my lovely Ryan, who has been my greatest motivation and inspiration, showing me the true meaning of hard work and perseverance. This thesis is particularly dedicated to you, for being my pillars of strength and love throughout this challenging but rewarding experience.

Declaration

All of the research mentioned in this thesis has been carried out by the PhD candidate, and none of it has been presented to support an application for another degree or certificate at this university or any other educational institution.

Abstract

The construction industry can be identified as one of the least digitized industries in the world, drastically underperforming less in terms of profitability, productivity, reliability, efficiency, and safety in comparison to the global economy than its average potential. Plus, the fact that the UK construction industry is usually criticised for being fragmented, wasteful, reluctant to innovate, and ineffective at utilising proper knowledge throughout the industry. For this reason, advanced technology referred to as “Smart Construction” is increasingly being used in the construction industry to increase decision-making and improve productivity. Actually, smart construction by employing construction resources such as devices, components, machinery, and people aimed to transform digital technologies in the construction industry.

So, for implementing smart construction by utilizing digital tools and techniques, Industry 4.0 or the fourth industrial revolution has been created to convert the construction industry in the direction of further digitally developed trades. Following Industry 4.0 and digital transformation concepts, numerous aspects of the construction phase have changed as a result of Industry 4.0 technologies such as Internet of Things (IoT), Cloud-computing, Cyber-physical systems, Automation, 3D printing, Robotics, and so on. Internet of things (IoT) as a crucial part of the industry 4.0 technologies has a significant role in advancing the possibilities of smart construction concepts in a variety of construction phases.

This research seeks to evaluate the role of the internet of things (IoT) in enhancing the performance of the UK construction industry. Furthermore, in terms of modern construction methods such as smart assembly, offsite construction, and lean philosophy, this research seeks to develop the framework, presents the applications of IoT, and identifies the emerging benefits and drawbacks of IoT applications in the UK construction sector. The developed framework will be useful for stakeholders to adopt and understand the impact of the fourth industrial revolution technologies such as IoT applications in the UK construction sector.

Also, in order to accomplish the aim, objectives, and explore the research questions that are set to this research, qualitative method approach is adopted in this research. Qualitative data collected through 38 semi-structured interviews from construction professionals involved in the digital transformation of the UK construction sector. Internal and external drivers for implementing the Internet of Things (IoT) were found. In addition, the challenges recognised from the numerous areas of IoT applications adoption in the UK construction sector, classifying into three groups including technological, cultural, and economic. Also, the key influencing factors for implementing the Internet of Things (IoT) were identified including cost, usability, leadership, technology awareness, staff training, and company size. Finally, a framework developed by analysing the data and evaluated through the UK construction sector.

Keywords: Industry 4.0, Digital Transformation, Internet of Things, Smart Construction

Chapter 1. Introduction

This chapter aims to provide the reader with an overview of the research with a framework to support their understanding. It includes the background and context of the research, justification and problem statement, aims and objectives, research questions, limitations of the study, contribution to the knowledge, and thesis structure.

1.1 Background and Context to the Research

According to Lombardi and Barber (2011), there is a view that long-term performance difficulties have remained to hinder the UK construction industry to be one of the most productive industries. Mahesar (2021) claimed that several clients are unsatisfied with the overall performance of the construction industry, and disappointed with the level of the construction industry's productivity. Furthermore, it is acknowledged that the construction industry commonly has huge concerns about the delivery of projects on time and under budget (Love &Skitmore, 2012).

A series of significant reports on the construction industry, including the Latham Report Latham (1994) and the Egan Report Egan (2002), have been issued to explain some of the underlying issues in the construction industry such as discontinuity, adversarial attitudes, labour shortage, and fragmentation. To address these issues, technology managerial innovations will be conducted to help the construction industry to improve productivity and profitability (Kaplinski, 2018). So, new construction tools, techniques, and technologies particularly smart construction concepts including the Internet of Things (IoT), Augmented Reality (AR), Robotics, 3D printing, Building Information Modelling (BIM), Cloud Computing, Syber Physical Security Systems and so on have emerged against this background (Guo, 2021; Kang, 2022; Tezel, 2021).

So, Industry 4.0 has emerged as a viable technology for expanding and integrating manufacturing and industrial processes at both the intra- and inter-organizational levels (Ilter, 2022). Following the recent development in Information and Communication Technologies (ICT), Industry 4.0's innovations and technological advancements will provide a range of workable solutions to address the expanding demands for manufacturing sectors' informatization (Jung, 2021).

The Internet of Things (IoT) is one of the industry 4.0 technologies that aimed to enhance the safety and quality of service, reliability, adaptability, portability, performance and security of smart construction and its infrastructures (Sun, 2021; Haghighi, 2020; Panteli, 2021; Ruan, 2021). IoT not only be able to communicate with real-world entities, but also can have access to vital information from the real world in addition to maintaining their real identities in the virtual world (Carpio, 2021). The construction industry has been faced with several challenges to adopt IoT in the construction environment including Cyber data security, data formats, and data ownership (Craveiro, 2021). For example, byincreasing connectivity and utilizing communications protocols between tools, equipment, and people, the requirement to protect system data and manufacturing lines from cyber security threats increases drastically (Jung, 2021).

In terms of using Big Data with diverse annotations of the data entities, it is getting more challenging to consolidate diverse types of data with various semantics for advanced data analytics (Kang, 2022). Furthermore, the investment issue is one of the significant challenges for the majority of the new technology-based initiatives in the construction industry (Oesterreich, 2021).

The challenges are unique and need particular efforts to tackle the challenges by implementing of IT solutions with the appropriate investment of the value chain at any stage of the construction process (Waidyasekara, 2021). So, with the current trend of digital transformation and increased use of data in the construction industry, this research attempts to develop a framework for the implementation of the Internet of Things (IoT) application that will be useful for stakeholders to understand and impact of IoT adoption in the UK construction sector.

1.2 Justification

In terms of adopting new technology in the construction industry, this has always been identified as conformist and traditional (Li, 2020). This is one of the significant reasons that the construction industry has lagged behind most other industry sectors (Papadonikolaki, 2022).

Also, in terms of innovation and renewal, the construction industry could be recognized as a low-tech industry with low levels of activities associated with innovation (below 2% annual investment in R&D) (Aigbavboaa, 2018). In addition, strong interdependence between the numerous supply network partners such as retail, construction contractors and subcontractors, suppliers, architects, and manufacturers will usually become an obstacle to innovation (Wang, 2021). The conservation characteristics of the construction industry deliver noticeable obstructions to introducing new technologies and initiatives to the sector, whether itbe new products, methods, tools, techniques, or market development (Cheng, 2020). In order to improve the efficiency and credibility of the construction industry, a number of initiatives have been commenced, including re-valuing construction, digital construction, partnering, etc. (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020).

Although each of these initiatives has substantially created value for the individual companies, none of them has specifically addressed the basic issue of developing a more systematised approach to continuous creative activity in the sector (Panteli, 2021). Such a plan and approach will definitely require addressing the distinct contextual features associated with the construction industry and how they impact innovation (Carpio, 2021). According to Lombardi and Barber (2011), in the UK, the vast majority of enterprises are SMEs (99%). Despite their significance, limited studyhas been published to explore the impact of implementation, adoption, and usage of information and communication technologies (ICT) in UK SMEs (Mahesar, 2021; Rau, 2020; Elghaish, 2021; Babalola, 2021).

Following adopting the new tools and technologies such as Big Data, Cyber security systems, Cloud Computing, and the Internet of Things (IoT) in the construction industry, smart systems have been extensively researched for their potential in improving occupational health and safety (OHS), streamlining work procedures, alleviating adverse environmental impacts, enhancing productivity, and creating value for society (Mahesar, 2021; Rau, 2020; Elghaish, 2021; Babalola, 2021). Furthermore, advancedsmart systems by implementing augmented reality (AR), Internet of Things (IoT), Digital Twins, and virtual reality (VR) have been developed for applications including quality and progress management, OHS training of construction workers, facility management, and site monitoring (Elghaish, 2021; Guo, 2021; Kim, 2021;

Haghighi, 2020). With a broad perspective on smart tools and technologies in the construction industry, Xu (2018) has presented the conceptual characteristics of smart construction objects (SCOs) and described their potential applications and fundamental properties (Xu, 2018). Smart construction systems by representing the dynamic research area attempted to encourage SMEs to use digital tools and techniques, however, their implementation and adoption by the construction industry are contentious (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020).

After interviewing several construction workers from different construction companies, they responded positively about the effectiveness of smart construction system, especially when thehead office personnel or system developer is involved (Babalola, 2021). However, it doesn't take long for conventional construction methods to emerge again, which Adekunle and Oyegoke (2004) humorously describe as having not altered in two thousand years. Actually, when a project's delivery is being pressed for time, money, or quality, such backward shifts are more likely to occur. Nowadays, smart systems have been treated as a potentially disruptive opponents ratherthan as a natural, endogenous ally (Adekunle & Oyegoke, 2004). Also, developers of smart construction systems believe that being hesitant to adapt to change is a significant part of any industry's culture (Ahankoob, 2021; Craveiro, 2021; Ilter, 2022; Jung, 2021; Kang, 2022).

In addition, research and development (R&D) on smart construction systems are also hampered by obstacles (Oesterreich, 2021). By incorporating BIM, VR, air drones, sensing technologies, robotics, AR, and the IoT, today's smart construction systems could potentially render construction the most cutting- edge industry (Waidyasekara, 2021). Due to practitioners' hesitation to adopt new tools and technologies as they disrupt established construction processes, system developers have restricted capabilities (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020).

The implementation of smart systems based on building information modeling (BIM) is a typical instance. Information is the key to BIM, so, as-built data should be synchronised with a model in real-time to facilitate construction decision-making (Jung, 2021). If practitioners must manually synchronize data and information, they will not use such a model. So, in this case, utilizing new technology such a BIM could be too intrusive to be a natural ally of construction. If technological innovations are meant to aid in the development of smart and modern construction, this gap and disconnection between system adopters and system developers have to be clarified and addressed (Liu,2022; Papadonikolaki, 2022; Sun, 2021; Wang, 2021).

BIM is, however, being adopted more widely in the UK as a result of the UK Government's substantial drive to mandate the utilise of collaborative 3D BIM for its centrally acquired built environment assets as of April 4th, 2016 (Xue, 2018). By establishing a step change in the asset lifecycle as well as the project delivery process, the mandate for BIM aims to improvethe industry's overall performance. A change in culture is required for the process of project information digitization, from the initial planning project phase to the closure of the project (Babalola, 2021; Cheng, 2020; Elghaish, 2021). Additionally, in order to accomplish such a transition, technology-based business procedures must be implemented, which are achievable by an innovative set of competencies and skills (Guo, 2021; Liu,2022; Papadonikolaki, 2022; Sun, 2021; Wang, 2021).

In principle, BIM not only will be implemented to be more operationally competent for its owners and provide a safer and more productive environment for its occupants, but also can be applied to improve the efficiency of the built asset lifecycle (Elghaish, 2021). As a result, Key industry stakeholders including contractors, client organisations, suppliers, and consultants are graduallyincorporating BIM into their various practices (Babalola, 2021). On the other hand, the maturity of the businesses to manage the adoption will greatly influence the degreeto which BIM can be implemented successfully to maximise its benefits (Waidyasekara, 2020).

Actually, the benefits of using BIM will be constrained without a clear client mandate, despite the fact that numerous organisations along the supply chain may have been adopting it to increase collaboration and efficiency (Sun, 2021; Wang, 2021). According to Muller (2017), clients not only can play a pivotal role in encouraging the sector to embrace change, but also can significantly contribute to accelerating the innovation process. Additionally, recent research demonstrates that clients would encourage innovation to achieve critical advantages of BIM adoption, such as improve information and facility management, cost and time savings, and real time monitoring (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020).

Clients, however, are less optimistic than the rest of the sector that smart technology such as BIM could accomplish the numerous targets and goals outlined in the Government Strategy (Jung, 2021). BIM has still not been widely adopted across the construction industry for some significant reasons, particularly because of the client fear and a lack of awareness of the advantages of using it as well as the settings requirements to realise these benefits (Kim, 2021; Haghighi, 2020). In order to achieve the greatest value across every phase of the BIM process, clients must thus fully aware the needed organisational skills as well as the supporting competencies and procedures to successfully implement this new technology into the construction industry (Guo, 2021; Liu, 2022; Papadonikolaki, 2022; Sun, 2021; Wang, 2021).

By considering and integration of BIM through the innovative tools and technologies, cloud computing technologies, Artificial Intelligence (AI), and the Internet of Things (IoT) would provide new opportunities for developing innovative applications across a wide range of industrial sectors (Jung, 2021). Such innovative technology could stimulate a new wave of reliable, safe andsecure, available, and highly dependable smart applications. (Wang, 2021). Other benefits of using these technologies to build smart applications are including safety and security in industrial settings,real-time monitoring, and logistics improvement (Papadonikolaki, 2022; Sun, 2021).

According to Parn (2021), systems that deploy artificial intelligence (AI) methods on IoT-generated data flow, which is subsequently processed in the cloud, have a very low level of technological readiness. However, one of the principal challenges is that these innovative technologies such as cloud system, IoT, and AI must be fully developed to address varied quality-of-service needs for data processing and communication (QJ, 2020). Huge volume, velocity, veracity, and variety are just a few of the characteristics of IoT-generated data. In order to address these properties, software-defined networking, application migration,and cloud application-adaptation approaches attempt to achieve smart application systems in a real-time situation (Guo, 2021; Liu, 2022; Papadonikolaki, 2022; Sun, 2021; Wang, 2021).

Furthermore, a variety of non-functional characteristics of smart applications must frequently be maintained, including availability, storage, high performance, computing and networking services, privacy, reliability and dependability of the data, and security (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020). Also, emerging cloud technologies aim to considerably improve lower operational costs, effective utilisation of computing and networking resources, the restricted operation to geographic areas, greater use of renewable energy sources, and greater energy efficiency (Ahankoob, 2021; Ji, 2022; Li, 2021; Oesterreich, 2021).

Moreover, cutting-edge technologies such as the big data, internet of things (IoT), cloud computing, and cyber-physical systems are transforming the traditional methods of planning, designing, and implementing of the construction projects (Waidyasekara, 2021). In order to improve business value, profitability, and productivity in the construction industry, Industry 4.0 and principles of design for manufacturing and assembly have positively transformed the construction industry to be considered as a technical manufacturing process with massive opportunities by using cloud computing, IoT, and Big Data for and making informed decisions and improving operations at numerous phases (Elghaish, 2021; Guo, 2021; Kim, 2021; Haghighi, 2020).

By considering the advancement in artificial intelligence (AI) and the growing market of low-cost sensors, the Internet of Things (IoT) ecosystem can able to generate and transform massive amounts of information and data through its integrated layer of software, hardware, and internet connectivity due to improving the overall productivity of the construction industry Ahankoob, 2021; Ji, 2022; Li, 2021; Oesterreich, 2021). As a result, in the current digital transformation of the construction industry, smart construction has been described as the capability of utilising digital tools, and techniques to improve efficiency and profitability (Ahankoob, 2021; Craveiro, 2021; Kang, 2022).

Also, it can be identified as a transition from the traditional methods of construction to manufacturing by increasing the usage of offsite fabrication and standardised components (Kang, 2022). So, in terms of digital transformation and smart construction concepts, increasing the usage of Big data will present tremendous application opportunities for the Internet of Things (IoT) in the construction industry (Craveiro, 2021).

Therefore, the key aim of this research is to define and demonstrate the possible research areas connected with the Internet of Things (IoT) and UK construction sector. So, in order to answer persistent questions and uncover the root cause of the dilemma, deep investigation is required.

1.3 Research Questions

The following questions are expected to answer the aim and objectives addressed, and it will be required to deliver the necessary information to address and answer the presented questions that are as follows:

1. With the integration of the Industry 4.0 applications and digital technologies that are currently used in the UK construction industry?

2. To what extent can Industry 4.0 technologies, particularly IoT application impact on the UK Construction sector?

3. What are the significant drivers and barriers for implementing the IoT in the UK construction sector?

4. What are the considerable factors that could influence stakeholders to adopt the industry 4.0 technologies such as Internet of Things (IoT) applications in the UK construction sector?

1.4 Aim and Objectives

1.4.1 Aim

This research study is aimed to develop a framework for implementation of the Internet of Things (IoT) application in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT implementation in the construction industry.

1.4.2 Objectives

To achieve the aim of this study, the research objectives are described as follow:

1. To examine digital transformation theories and concepts and their applicability to the UK construction industry.

2. To determine the industry 4.0 approach, particularly key principles of Internet of Things (IoT) adoption across the Uk construction sector.

3. To establish the main drivers, barriers, and challenges in the process of increasing digitalisation particularly implementing the Internet of Things (IoT) application in the UK construction sector.

4. To analyse the key influencing factors for implementation of the Internet of Things (IoT) application in the UK construction sector.

5. To develop a framework for implementation of the Internet of Things (IoT) application for stakeholders to understand the impact of IoT implementation in the UK construction industry.

6. To validate a framework for implementing the IoT applications in the UK construction sector.

1.5 Limitations of the Study

Construction industry has a crucial role to the economic growth. Although, the operation of various other industries is dependent on the construction industry, this sector has the worst records in terms of safety,efficiency, profitability, and reliability (Craveiro, 2021). Through the utilisation of cutting-edge digital technology, current developments in the construction industry aim to mitigate operational inefficiencies. Innovative technologies such as Cyber-Physical Systems, Cloud Computing, Big Data, and the Internet of Things (IoT) have revolutionized the method that construction projects are designed and implemented traditionally (Ahankoob, 2021; Craveiro, 2021; Kang, 2022).

This study seeks to develop a framework for implementing of the industry 4.0 technologies such as Internet of Things (IoT) applications in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT adoption in the construction sector. For this purpose, a set of limitations exist; such as possible time constraints and approaching the knowledgeable construction professionals that are the two significant examples of existing limitations. For example, some of the small construction companies could not invest to purchase digital tools and equipment to adopt and implement IoT application in their site activities because of the financial issues. So, their project managers or even their employees could not get this opportunity to be trained for using the smart technologies. Also, some of construction companies are still hesitate to adopt and implement digital tools because of the high cost of smart technologies and maintenance .Also, lack of experience and not having enough knowledge to use these smart tools could be another issue to find the knowledgeable construction professional that implemented innovative technology in their job activities. (Ahankoob, 2021; Craveiro, 2021; Kang, 2022).

On the other hand, initially, the researcher tried to use the mixed-methods by combining both qualitative and quantitative data collection that can help to validate a proper findings and provide a more comprehensive understanding of the research topic on implementing IoT applications in the UK construction sector. However, after sending the online questionnaire to more than 100 project managers that working in the UK construction sector and receiving just %10 feedback from them, the researcher decided to just focus on the qualitative research method by interviewing from the project managers in the UK construction industry to collect the proper data for analysing to get the final results. So, after collecting and analysing data, the developed framework should beuseful for construction organisations in the UK Construction sector.

1.6 Contribution to knowledge and practice

In terms of contribution to knowledge, it is extremely crucial to design development, evaluate and examine frameworks, and provide the business models for the Internet of Things adoption in the UK construction sector, emphasizing on people, machinery, and digital technology. So, this research intends to investigate the key influencing factors for the implementation of Industry 4.0 technologies particularly Internet of Things (IoT) in the construction organisations, assisting the stakeholders to understand the impact of internet of things adoption in the UK construction sector.

In terms of contribution to Practice, the framework of integration of Industry 4.0 technologies and construction industry was introduced through the five Uk construction companies. This innovative tool shall then be subjected to continuous validation and to record its performance and measure the expected improvements across the projects and organisations. Based on this improved comprehension, organisations could be given recommendations for the effective deployment of new technologies while taking into consideration the distinctive features and necessities of the construction organisations

The research study benefits UK construction industry employees, decision-makers, and policymakers by presenting a framework for implementing Internet of Things (IoT) applications in the Uk construction sector, resulting in:

- Examining the term “digital transformation” in the construction industry.
- Providing decision-making support for identifying levels and stages of Internet of Things (IoT) implementation.
- Facilitating information flow between construction industry organisations and technology consultants for providing suitable technological solutions.
- Enhancing construction company digitalization awareness.
- Enhancing awareness of the Internet of Things (IoT) implementation drivers in construction projects.
- Enhancing awareness of the Internet of Things (IoT) implementation challenges in construction projects.
- Describing the key influencing factors (KIFs) for implementing the Internet of Things (IoT) applications in the construction industry.

1.7 Thesis structure

Chapter 1: This chapter aims to provide the reader with an overview of the research with a framework to support their understanding. It includes the background and context of the research, justification and problem statement, aims and objectives, research questions, limitations of the study, contribution to the knowledge, and thesis structure.

Chapter 2: This chapter provides a literature review on the construction sector, digital transformation, Industry 4.0 technologies, Building Information Modelling (BIM), Internet of Things (IoT), and evaluates the impacts of these technologies in the UK construction industry.

Chapter 3: This chapter outlines the research methodology utilised to investigate the research questions regarding the impacts of Internet of Things (IoT) implementation in the construction industry, addressing the research process, methods, and strategies. It also provides the underlying research findings.

Chapter 4: This chapter explores the adoption of implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector, focusing on the process of embracing new solutions that could impact the productivity of organisations. This chapter analyzes the findings obtained from the literature, also complemented by 38 semi-structured interviews with construction professionals in the construction sector. Then, thematic analysis generates themes, revealing strong evidence of typical smart tools and technologies such as the Internet of Things (IoT) applications in the UK construction sector.

Chapter 5: This chapter explores the drivers to implementing industry 4.0 technologies particularly, Internet of Things (IoT) applications in the UK construction sector, based on data from 38 semi-structured interviews with construction professionals in the UK. The findings are compared to relevant literature and are grouped into internal and external drivers.

Chapter 6: This chapter discusses the significant challenges and barriers to implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector, based on 38 semi-structured interviews with construction professionals in the UK. The findings are compared to appropriate literature and based on participants' perceptions. Actually, the data analysis reveals the significant challenges in the construction sector for implementing the Internet of Things (IoT), categorized into three sections including technological, cultural, and economic aspects.

Chapter 7: This chapter discusses the key influencing factors (KIF) for the implementation of Industry 4.0 technology such as the Internet of Things (IoT) in the Construction sector. The findings have been constructed on qualitative data collected through 38 semi-structured interviews with construction professionals in the construction sector, analyzing their perceptions and comparing them to relevant literature.

Chapter 8: This chapter provides a developing framework for the implementation of the Internet of Things (IoT) in the UK construction sector, considering previous investigation findings. It presents a better understanding of drivers and barriers to implementing the Internet of Things (IoT) applications integrated with smart devices and offers an interpretative strategy for the social reality of the construction sector.

Chapter 9: This chapter will discuss the conclusions and recommendations of the research study based on the findings and results of the investigation. This chapter also presents recommendations for the body of knowledge, complemented by the body of practice, highlights future work opportunities, and discusses the research process.

The researcher in this study analyzes literature and interviews findings to understand the impact of implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction industry, focusing on drivers, barriers, and key influencing factors. This study Utilized the data to develop a framework for implementing the Internet of Things (IoT) in the Uk construction sector. Figure 1 will demonstrate the research road map in this journey as:

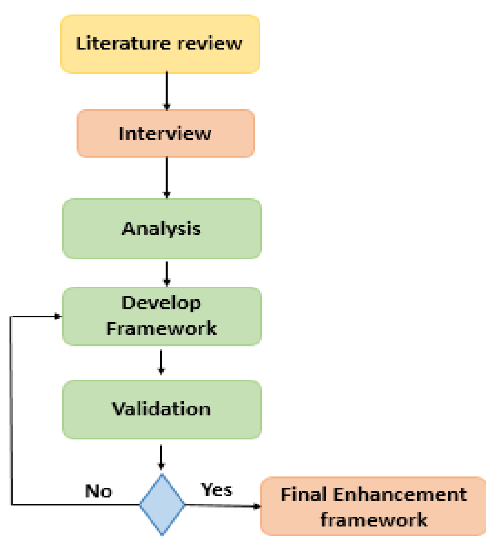


Figure 1 Research Road Map

Chapter 2. Research Literature

This chapter provides a literature review on the construction sector, digital transformation, Industry 4.0 technologies, Building Information Modelling (BIM), Internet of Things (IoT), and evaluates the impacts of these technologies in the UK construction industry.

2.1 The UK construction industry

The construction industry is a significant contributor to the UK economy, accounting for 6.5-8.0% of gross domestic product (GDP) and generating £69 billion in value added annually (HM Government, 2022). Construction industry could be considered into several sections including "provision of construction-related professional services, construction contracting industry, and construction-related materials and products" (Lombardi & Barber, 2011).

The UK construction industry as a significant part of the UK economy has been always criticised for being fragmented, having failed attempts to deliver projects on time and under budget for the last five decades. This sector has been suffering from suboptimal building quality, excessive costs, and time delays. In addition, adversarial relationships between different stakeholders were another factor that impacted adversely on the productivity level of this sector (Duncan, 2011). So, in order to promote improvements in predictability, profitability, and productivity, an extensive amount of government reports have been issued (Lombardi & Barber, 2011).
The Productivity Growth of the construction industry is illustrated in Figure 2 (Office for National Statistics, 2022):

Figure 2 The Productivity Growth in the UK

2.1.1 An historical overview of UK Construction reports

Since 1944, the government has frequently requested research studies to analyse its practices, present feedback, recommendations, and eventually improve its outputs. The numerous in-depth reports just commenced with Simon's 'Placing and Management of Building Contracts' (1944), which dealt with organising the UK's post-World War II reconstruction with the aim of matching the demand and supply, boosting productivity and profitability to assure the redevelopments of a country devastated by war.

It's interesting that instead of formulating solutions, this report sparked a discussion on how the construction process could be organized (Adekunle & Oyegoke, 2009). Survey of Problems Before the Construction Industry' by Emmerson (1962) was the next publication. He claimed that productivity developments had been hampered by the sector's repeated "boom and bust" cycle, not by challenges the sector had created by its action (Moodley & Preece 2008). However, it acted as an introduction to Banwell's 1964 report, "The Placing and Management of Contracts for Building and Civil Engineering," which was substantially more significant.

This report highlighted difficulties similar to those identified by its predecessors, including mismanagement of contractual and process challenges. Actually, recommended a more adaptable method to contractual processes, eventually suggesting improvements to the contractor appointment process. At the result, the professional bodies such as the Royal Institution of Chartered Surveyors (RICS) and the Royal Institute of Chartered Architects (RIBA) acknowledged these recommendations even though the suggestions did not include means of measurement or targets.

The next report wouldn't bepublished by Latham (1994) for an industry that was still facing incredible challenges for another 30 years. The key aim of this report was to reduce litigation, improve profitability and productivity, and motivate Government backed reforms by encouraging contractors, sub-contractors, designers, and clients to alter the methods and techniques in which they stimulate, operate , and conduct cultural transformation from within the construction industry (Adekunle & Oyegoke, 2009).

This report is probably most widely recognised for its discussion of contractual challenges in relation to payments and litigation. Standards were the main concern for Egan (1998), who proposed for radical reform which approached on, innovation of process and product development, innovation in continuous improvement, innovation of cultural change, innovation in business and projects, and value addition. This study acted as a catalyst for the target setting, introduction of the vital Drivers for Change, and implementation of the Key Performance Indicators (KPI) to track progress (Murray 2008).

Egan (2002), four years later, published a substantial report emphasised the achievable benefits based on team working, strategic partnering, and transferring knowledge and expertise. This resulted in the development of new contract forms, particularly the New Engineering Contract (NEC), which promoted a less adversarial method of construction. Actually, the sector experienced little improvement as a result of Egan's 1998 intends, which were to be thoroughly investigated in the next report to evaluate the troubled construction industry (Adekunle & Oyegoke, 2009).

Since Egan was tasked with defining the improvement agenda for the following decade, the report considered the construction industry's development. While certain improvements had been accomplished, it could be concluded that the construction industry had fallen short of Egan's objectives. Profitability and safety, both were identified as critical improvements, however, other areas had annual improvements of less than 3%. The notable obstacles to improvement were defined as lack of strategic commitment at Government levels and senior management, business strategic models based on short term approaches, poor integration in the supply chain, investment issues, and fragmented industry.

Also, the review outlined a considerable plan for the future of UK construction, and stated that one of the key challenges facing the construction industry is delivery of the environmental construction projects that facilitates the emergence of a low-carbon economy (Constructing Excellence, 2015). Actually, the Government Construction Strategy (2011)'s intention was to promote growth by enabling more construction to be accomplished with the limited public funds that were presently available. This report not only defined the Government as a pivotal player in enhancing the performance of the sector, but also called for change in obtaining greater value for money in the construction industry. The Government, as one of the key clients of the sector, called for the introduction of the significant change in the relationship between construction industry and between public authorities (Cabinet Office, 2011). This would make sure that the Government always receives a good deal, the country receives the economic and social Construction requirements in the long term (Cabinet Office, 2011, p 3).

By considering the public procurement and conducting a comprehensive set of policies based on cost benchmarking, standards, and value for money, the government focused on reducing costs (up to 20%) by the end of the parliament. By 2016, as part of implementation of BIM phase, all centrally procured construction contracts would utilise fully collaborative 3D BIM. In response to this plan, 52.9% of clients in the public sector altered some aspects of their business practices, with 5% making major adjustments (Dave, 2018). More public sector clients implemented BIM on one of their practices and projects, with 38% of them reporting success with BIM adoption (Tanga, 2019).

Figure 3 Construction 2025 targets, adapted from Construction 2025 Strategy

The later strategy, Construction 2025 strategy (2013), aims to present a long-term worldwide vision of the construction industry. As demonstrated in Figure 3, these objectives positionedthe construction industry to evaluate its performance, identify innovative methods to reduce costs, reduce carbon emissions, and accelerate project delivery time.

So, the skilled, inspired, qualified, and varied workforce is required for the construction industry to fulfil the current vision of being at "the heart of our future, resource efficient, modern, low carbon, and globally competitive economy." In the current vision, sustainable solutions, greater digital design, and new tools and techniques are being emphasised in order to improve productivity, enhance efficiency, and reduce costs. The intended objective of Construction 2025 is to further improve savings by up to 33% by 2025, increasing BIM usage and enhanced supply chain efficiency.

By considering that the UK government is driving for its adoption, BIM is once more considered as being crucial to achieving these objectives (Xue, 2018). Finally, in 2016, the Farmer Review of the UK Construction Labour Model noted effective recommendation, stating that if the construction industry could be achieved greater performance to enhance productivity and profitability if the challenges defined in the previous publication and reports are addressed.

Farmer (2016), stated that the construction industry is required to alter its culture immediately, considering implementing new technology development in other industries, it could be the proper time to prevent further tremendous pressures for the lack of workforce in this industry. As a result, regardless of motivation for cultural change, conducting this transformation requires external action through the construction industry. The government is urged by this report to promote industrial transformation and to establish the necessary frameworks to facilitate the modernization of the construction industry (Farmer, 2016).

So, in the next chapter,the revolution of smart construction, digital transformation, and Industry 4.0 technologies particularly the Internet of Things (IoT) will be reviewed and discussed.

2.1.2 UK Infrastructure sector

The Economist defines infrastructure as the "plumbing of the economy," including airports, roads, container ports, and railways. Also, according to The National Infrastructure Commission, economic infrastructure can be defined by digital communications, energy, water, flood risk management, and transport. In addition, in various infrastructure programs and publications, the government also incorporates social infrastructure, such as hospitals and schools(Xue, 2018).

The UK economy faces long-term challenges, with slow economic growth in recent decades. For example, to tackle climate change, more action is required, and economic infrastructure could be one of the significant solutions to overcoming these challenges. The effective infrastructure supports growth by cutting costs and improving connectivity. Since economic infrastructure accounts for over two thirds of the nation's greenhouse gas emissions, decarbonizing important sectors like electricity, heat, and transportation is essential to achieving climate goals (Farmer, 2016).

Infrastructure plays a crucial role in growth, as it provides labor markets and housing, enhances productivity and facilitates technological change. Improving infrastructure services can lead to lower costs for firms and households, while also enabling to get high-quality mobile and broadband networks, which are essential for the development of effective online services. Investment in infrastructure will be needed in order to address persistent regional financial inequalities (Office for national statistic, 2022).

Underinvestment in resilience has been highlighted by recent challenges in the UK infrastructure sector. The UK's water resources are vulnerable to water resources fragility, and climate change is making resilience enhancement more pressing. Labor shortages is another challenge that could disrupt the rail network. Reaching net zero also faces challenges from low investment levels. So, for tackling these crucial challenges, the government by publishing several documents, articles, action plans, and so on, attempts to encourage stakeholders to invest in adopting and implementing digital technologies to improve productivity and profitability (Xue, 2018).

So, this research seeks to develop the framework, presents the applications of IoT, and identifies the emerging benefits and drawbacks of IoT applications in the UK Construction sector. The developed framework will be useful for stakeholders to adopt and understand the impact of the fourth industrial revolution technologies such as IoT applications in the UK Construction sector. Figure 4 shows the investment in the infrastructure sector in the UK 2010 to 2020 as:

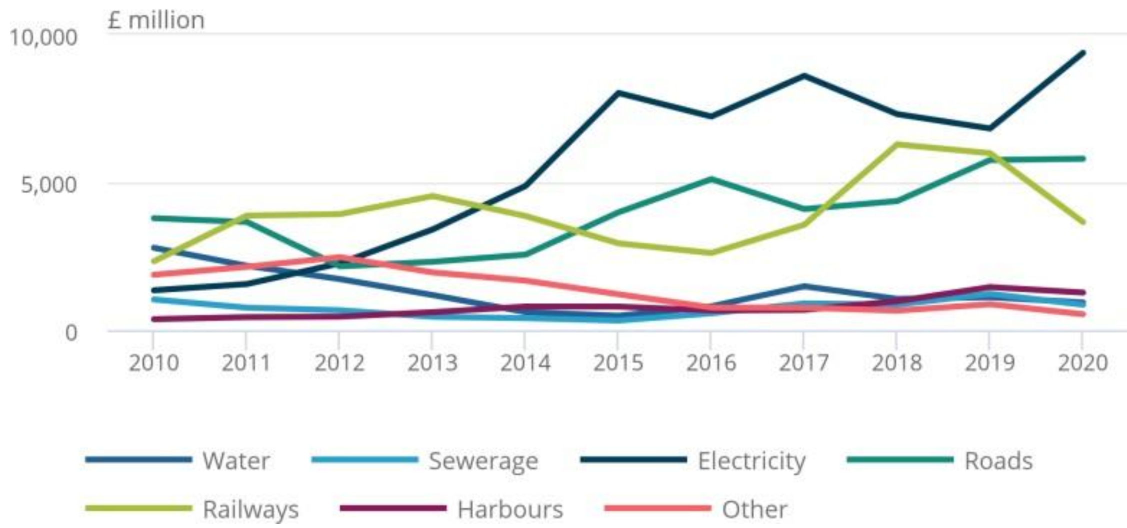


Figure 4 Investment in the Infrastructure Sector in the UK

2.2 Digital Transformation

In the modern era, digital transformation will be identified as the utilise of digital tools and techniques such as Cyber Physical system, 3D printing, Virtual Reality, Big Data, Cloud Computing, Robotics, Internet of Things (IoT), and so on to change the nature, culture, and process of the industry's environment by providing value-producing opportunities and reshaping organizations, services, and products-based cloud services (Ahankoob, 2021).

Digital channels are the platforms and devices to how the entire organisation innovates, competes, and its impacts are impossible to ignore to increase the efficiency and productivity in manufacturing and business Industry (Craveiro, 2021). Some of the significant opportunities of adopting digital transformation for any industry are including such as reduce the burden of management and data storage in companies, enhance the customer satisfaction, increase the employee productivity, new revenue growth and increase the profitability, increase the operational efficiency and convenience, increase the same high- quality technical standard, and obtain competitive advantage to stay relevant in a crowded market (Ilter,2022; Liu, 2018; Kang, 2016).

Enhancing the digital customer experience can be lead to take an understanding of its business value (Ji, 2022). So, Jung (2021) claimed that there are several challenges to meet consumer expectations based on the digital experience. The most important of these challenges are including adopting ‘digital-first’ mind-set, searching for the right alliance partner, building digital willingness amongoperational levels and middle management, shortage of suitably trained professionals, and managing change lack of competing and strategy priorities (Jung, 2021).

2.3 Construction Industry and Digital transformation

The World is changing, the construction industry is considered as one of the pivotal industries that has usually been late in technological progress which should be changing at the earliest time to grow the quality of life (Ahankoob, 2021).

Over the last 50 years, some initiatives and improvements have been made to transform the nature and culture of the construction industry from traditional methods to the digital one (Craveiro, 2021). These improvements attempted to explore the solutions for increasing the profitability, efficiency, and productivity in the construction Industry. For this reason, radical change shouldbe conducted in any stages of construction sectors to get the ideal results (Ilter, 2022).

For instance, adopting and conducting smart technology such as Building Information Modelling (BIM), which is recognised as one of the main predominant tools influencing the construction sector to get the higher productivity, has been discussed just in a context of theory for the last decade (Jung, 2021). But the Government by issuing some policy and standards attempted to encourage organisations to adopt and conduct BIM technology in their construction projects to deliver the projects in time and within budget. Recent research has demonstrated that over the last 20 years, the construction industry's improvement in productivity have not been sufficient (Waidyasekara, 2021).

Following the potential of digital transformation through the construction industry, digitization will be classified into four major groups based on the functions, departments, and individual divisions that are automation, digital access, digital data, and connectivity (Kang, 2022). Digital access identifies the accessibility of data by mobile tools to the local and internet networks. Digital data can be used to process and gather of data in the area of working site to achieve the real data and better usage (Li, 2021). Automation can be identified as the innovative tools and technologies that create self-arranging schemes. Connectivity covers the function related to synchronize andlink up the previously tasks (Kaplinski, 2018).

Although, changing the nature of the construction industry is a difficult task, however, utilizing the modern tools and techniques have massive advantages and benefits for increasing productivity, efficiency, and profitability such as lower cost and faster delivery time of construction projects (Oesterreich, 2021). According to Tanga (2019), Some of the significant barriers toadopt digital technologies in the construction industry are including low interoperability, inadequate of agreed standards, difficulties in recruiting and digital talents and young people, lack of skills and knowledge, the different levels of maturity between SMEs and large companies to adopt digital technology, cost of digitalisation particularly for SMEs, fear of drawbacks that could be resulting from adoption of the digital technology equipment (Fok, 2016; Stock, 2016; Tanga, 2019).

To overcome these challenges, the Construction Industry should provide an opportunity to enhance the productivity by implementing the digital tools and techniques instead of traditional methods along with industry 4.0 (Kang, 2022). Recently, construction industry businesses is attempting to improve value from digital skills acquisition, IT investments, and advanced digital infrastructure to investigate how construction projects can be designed, constructed and managed digitally (Jung, 2021; Li, 2021; Oesterreich, 2021; Panteli, 2021)

2.4 Smart Construction

Smart construction as a vital part of the smart city can be described as a connectivity between human, machine, resources, and internet connection by using digital tools, techniques, and technologies that aims to decrease waste, improve productivity, increase precision, faster delivery of the project, cut project costs, and accelerate sustainability in any stages of construction sector (Mahesar, 2021; Rau, 2020; Li, 2020; Boje, 2020) Also, the terms of Smart Construction will be identified as the new engineering management theory that could be conducted in the construction project environment to manage and improve the processes of construction project efficiently by implementing technical innovation (Tanga, 2019).

In addition, smart construction by implementing digital tools such as building information modelling (BIM), cloud computing, 3D printing and visualization, robotics, big data, ubiquitous computing, internet of things (IoT), and other advanced network attempts to meet the requirements of smart project function to increase the profitability and faster delivery of the project (Kang, 2022; Li, 2021; Oesterreich, 2021; Tezel, 2021).

Also, Ahankoob (2021) stated that various aspects of supportive system can complement the smart construction theory that are including as:

- smart construction is one of the significant parts of implementation of smart city;
- innovative technologies such as cloud computing, internet of things (IoT), 4D visualization, big data, ubiquitous computing, building information modelling (BIM), and cyber physical system can provide the technical support of implementing smart construction theory;
- principals such as lean construction, building life management (BLM), sustainable construction, and AEC projects management will produce theory basis for conducting the smart construction theory (Tezel, 2021; Jung, 2021; Wang,2021)

So, the idea and concept of the smart construction theory is defined to gain smart response to the personalized requires of various parties by using advanced network and information technologies through the construction project (Ahankoob, 2021; Ilter, 2022; Craveiro, 2021)

2.5 Industry 4.0

Industry 4.0 or fourth revolution of industry can be described as the new revolution for increasing utilize of automationand information technologies in the variety of industries particularly in the manufacturing environment (Kang, 2022; Oesterreich, 2021). The fourth revolution of industry has override three former revaluations including mechanization, electrification, and computerization to improve the productivity with massive advantages than the previous revolutions (Tezel, 2021). The first industrialrevolution was developed by utilising mechanical production facilities such as employing thewater and steam powers to gain the required energy (Ahankoob, 2021).

Then, the second industrial revolution was developed by using electrical energy to provide mass production. Then, the next one was presented by conducting electronic tools and information technologies in numerous industries that furthered automation production (Craveiro, 2021; Ilter, 2022). Also, fourth revolution of industry by increasing automation and digitisation of the industry environment provides the integration between people and complex physical machinery that can connect each other with the assistant of the information technology, sensors, software, and internet networks to control, plan, and predict for societal outcomes and better business (Kang, 2022; Tezel, 2021; Panteli, 2021; Li, 2020).

In essence, there are nine pillars toward exchanging data and automation of the industry by fourth industrial revolution technologies which are Additive Manufacturing, System Integration, Internet of Things, Cloud Computing, 3Dprinting, Autonomous Robot, Big Data, Augmented Reality, Cyber Physical System, and Simulation (Ruan, 2021; Carpio, 2021; Guo, 2021; Mahesar, 2021). These components by contributing digital technologies into the industry environment try to reconstruct production into an optimized, integrated, and automated production flow; therefore, bringing greater relation and efficiency among suppliers, contractors, clients, and producers through the manufacturing production and process (Kamblea, 2018).

So, by utilizing these technologies, Industry 4.0 by approaching various digital application is emerged for extending and integrating manufacturing processes at organisational levels (Ahankoob, 2021). In addition, the emergence of Industry 4.0 has been completed by development of the technological application and Information Communication Technologies (ICT). Actually, this development in Industry 4.0 has provided various effective solutions to the growing needs of digital information in the developing industries such as manufacturing and construction industries (Craveiro, 202; Ilter, 2022; Kang, 2022)

Also, it leads that the growing number of small and medium enterprises throughout the world have examined the benefits and advantages of adopting Industry 4.0 for the future’s complex industrial ecosystems (Oesterreich, 2021). Therefore, Industry 4.0 seeks to enhance productivity, profitability, and efficiency of various industries by adopting innovative technologies (Waidyasekara, 2021). Although the construction industry which is considerably lag behind other industries to adopt and utilise digital technologies at the different phases and processes of the construction,but Industry 4.0 could be one of the significant platforms to improve the productivity and profitability (Jung, 2021; Sun, 2021; Babalola, 2021; Boje, 2020).

The fundamental principles for conducting the industry 4.0 application are vertical integration system, end-to-end digital integration, and horizontal integration (Kang, 2022). The horizontal integration system includes the integration of the processes, data and IT systems that flows between different suppliers, customers, and companies to allow the closer collaboration with them (Tezel, 2021). In addition, end-to-end integration is aimed to customize the products due to reduce the internal operating costs. So, cyber- physical systems (CPS) will be required to conduct the digital integration across the entire value chain. Also, vertical integration involves integrating processes, data, and IT systems within a company, fostering cross-functional collaboration and resulting in a smart manufacturing system through product development, sales, manufacturing,and logistics (Waidyasekara, 2021; Boje, 2020; Guo, 2021; Kim, 2021).

2.6 Integration of Industry 4.0 and BIM in the construction industry

The term “Building Information Modelling (BIM)” refers to a digital technology that defines an engineering project integrating intellectual objects with their specific data possessions and instruction. Thus, each object's representation and internal features are available for presentation (Li, 2020; Papadonikolaki, 2022). The significant features of BIM are including coordination, optimization, visualization, and simulation. The ability to generate digital models and simulations of projects from the early stages of a construction project is one of the key advantages of adopting BIM. In addition, implementing BIM in the construction project provides fast calculations, displays replacements, reduces planning faults, and quantifies further costs (Waidyasekara, 2020; Babalola, 2021; Cheng, 2020).

Industry 4.0 by providing a huge scope in the digital area attempts to establish a new standard to utilise a digital tools and techniques in the construction project (Elghaish, 2021). BIM will accelerate and complete this process by gathering truthful digital information through every stages of the construction project lifecycle to reduce the faults, enhance productivity, and improve the budget (Cheng, 2020). So, BIM with its numerous digital practices and techniques will increase the workability of the project (Babalola, 2021). Schumacher (2016) claimed that thebenefits of digital information will be gained if BIM can be conducted at the early phase of theconstruction project. Also, based on the three-dimensional visualization dimensions, BIM is a technology that will be conducted in preparation of the construction industrialization to provide sustainable aspects of the project. Additionally, the nD model of the BIM could aid managers in selecting and determining how to use assembled parts (Wang, 2021).

Therefore, in the construction project, implementing BIM could decrease waste, enhance the quality and performance of the project, and reduce the delivery time (Cheng, 2020). In the construction stageof the project, Augmented Reality (AR) and BIM technology can incorporate together to transmit digital information to the physical parts. Also, utilising of digital processing and BIM application can lead to precise distribution of information and advanced management in the construction project (Waidyasekara, 2021; Jung, 2021; Li, 2020).

Furthermore, the conservation process, pre-fabrication assembly, manufacturer's design, and the combination of fabrication will be developed as a result of BIM technology's ability to provide valuable information (Cheng, 2020). It is obvious that the construction industryis considered benefits of digital transformation, smart construction concepts, and Industry 4.0 (Aigbavboaa, 2018). However, the construction industry is still lag behind other industries to adopt and implement the digital technologies. Actually, a small number of the construction industry’s stakeholders have yet embraced these digital tools and technologies to boost their profitability (Elghaish, 2021; Guo, 2021; Kim, 2021; Carpio, 2021).

2.7 Issues for adopting Industry 4.0 in the Construction Industry

In order to respond and adapt to the present dynamic market demands and requirements, the industry has developed from the initial stage of the implementation of mechanical systems to today's fully automated manufacturing processes as a result of the emergence of new tools and technologies (Li, 2020; Mahesar, 2021; Rau, 2020). Based on recent publication, some of the significant issues for implementing the Industry 4.0 inconstruction industry are flexibility, predictability, embedment and robustness to unexpected conditions (Craveiro, 2021; Ilter, 2022; Kang, 2022). Also, other fundamental challenges that occur by conducting the industry 4.0 are including as (Li, 2021; Oesterreich, 2021; Tezel, 2021; Babalola, 2021; Elghaish, 2021):

Big Data Manufacturing - integrity of the data is one of the biggest issues for conducting Industry 4.0tools and techniques particularly, in the construction industry that the data recorded from manufacturing system are very diverse and it can increase the challenges to incorporate diverse data repositories for advanced data analytics (Jung, 2021).

Investment Challenges - Investment issues for buying and adopting new digital technology can be an initial challenge for implementation of the Industry 4.0 tools and technologies in the construction industry that required a achievable plan to encourage the stakeholders to invest in adopting the new technology in the construction industry particularly, in the SME (Kang, 2022).

Mechanism and Intelligent Decision-Making - Lack of autonomy and sociality capabilities in today's system are the key issues that is required to represent the smart construction (Elghaish, 2021).

Cyber Security System - By increasing the use of standard communications protocols and connectivity for conducting Industry 4.0 tools and techniques in the manufacturing, the need to protect system data and applications from cyber security threats will be increased considerably (Oesterreich, 2021).

2.8 The Internet of Things (IoT)

The term "Internet of Things (IoT)" is recognized as digital and mechanical objects, machines, and tools that can have the capacity to receive and transfer data across the environmental networks (Haghighi, 2020; Panteli, 2021). Also, the Internet of Things (IoT) as a significant application of the Industry 4.0 is considered with the various connected application which rely on information technologies, advanced communication and networking, and sensory (Bhoslec, 2018; Moeuf, 2017).

Panteli (2021) stated that wireless sensor networks (WSN) and RFID are approached as the two significant application of using IoT through the manufacturing industry. In RFID technology, the microchips can transmit the information and data to readers through wireless communication system (Guo, 2021). Actually, users by utilizing RFID readers can able to monitor and track any objects tagged with RFID tags automatically. Also, RFID can be applied and conducted in various industries such as materials management, package delivery, retailing, transportation, and so on.

Mahesar (2021) claimed that there are significant issues for adopting RFID through IoT that are including as collision of RFID readings, standardisation, signal interference, integration.

Furthermore, by increasing utilise of the RFID through IoT network, devices requires more RFID security and safety as a cyber cecurity system that will be adopted in numerous areas of industries such as privacy protection, manufacture, business processes, and so on (Rau, 2020). Wireless sensor networks (WSN) is another devices of using IoT through the various industries that applies intelligent sensors for monitoring and sensing. Also, multiple applications of WSN can be conducted in numerous industry areas such as healthcare monitoring, industrial monitoring, transportation monitoring, and environmental monitoring. Therefore, the integration of applying RFID and WSN together can empower IoT application in conducting of the industrial services to enhance the performance of real time monitoring in industries (Haghighi, 2020; Kim, 2021; Ruan, 2021).

2.9 IoT Areas in the Construction Industry

Guo (2021) believes that adopting digital technology such as IoT application has an incredible impact in increasing the profitability, productivity, and faster delivery of the project in several industries (Mahesar, 2021). However, most of the companies are still in the process ofrealizing potential use cases. For this reason, the theory and idea of the innovations diffusion can be considered in industries to get the proper decision to implement the new technologies. The process of these activates are including as persuasion, decision, and then implementation (Ruan, 2021).

Ruan (2021) claimed that to consider the possible areas of IoT systems in the manufacturing and construction industry, several areas were identified that are including Facility Management (FM), Real-Time Monitoring (RM), Offsite Manufacturing (OM), Product Lifecycle Management (PLM), Onsite Assembly (OA), Cyber-Physical Systems (CPS), Handling and Logistics (HL), Design and Analyses (DA), and Energy Consumption (Haghighi, 2020; Panteli, 2021; Carpio, 2021; Guo, 2021; Mahesar, 2021).

Rau (2020) argued that the implementation of IoT applications could ultimately be put into practice throughout several stages of construction, such as planning, construction, monitoring, and facility management. Also, he claimed that the most of the IoT applications have been utilised for the record of the real-time monitoring and facility management in the significant areas of image captioning, health and safety monitoring, video capturing and streaming, and data sensing. In addition, IoT application for real-time data could be used in other areas such as facility management for reliability analysis and emergency response, automatic fault detection, predictive maintenance, energy consumption optimization, and energy balancing (Li, 2020; Mahesar, 2021; Stefanic, 2018; Calvo, 2018).

For instance, IoT application such as motion and Bluetooth low energy sensors can be utilised to record, track, and monitor the movement of materials, labors, and equipment in the construction projects sites (Carpio, 2021). Also, the tracking system that associated with the Building Information Modeling (BIM) can monitor the labor behaviors, moving paths, and resource status (Rau, 2020). In addition, incorporating BIM and real time sensory can capture the realistic environmental conditions of the construction sites to calculate the automatic crane operations,compactor's path, and equipment operator's instruction (Waidyasekara, 2021; Jung, 2021).

Furthermore, IoT application will be utilised in the areas of project management such as the product lifecycle management (PLM) (Aigbavboaa, 2018). Product Lifecycle Management (PLM) in the manufacturing industry can be identified as manage and collect the information on decision and process of the product across the product development phase. Also, products in PLM are disposed in the both level of an inter-organisational and intra-organisational that can be distributed in a collaborative environment (Kim, 2021). Therefore, it is crucial to consider that incorporating heterogeneous and distributed product data could cover various lifecycle phases with an adaptable framework (Ruan, 2021).

So, because of the huge volume of such diverse information, the involved information will be sophisticated for sharing and exchanging purposes. For IoT-based applications, Guo (2021) set up a programmable, adaptable, and open software platform application. This information model can approach into the every phase of the product lifecycle in order to link distributed product data across organisations. According to Carpio (2021) adopting IoT applicationcan increase the productivity of the modern manufacturing. Also, he claimed that the IoT environment consists of three layers: the IoT industry solutions layer, the IoT platform layer, and the IoT application layer.

The IoT platform layer can be described as a connection between digital devices to transmit, receive, and streams data and information from the selected digital devices to the application layer (Mahesar, 2021). The next layer of the IoT environment is the application layer that evaluates and considers equipment status with cognitive tools and techniques such as machine learning, automation, and data analytics to assess the dynamic complex elements (Kim, 2021). According to Woodhead (2018), Utilising IoT network data acquired through data analytics can assist inaccelerating timely decision-making. (Woodhead, 2018).

The industry solutions layer will be the last layer of the IoT ecosystem, adding knowledge to the application layer (Ruan, 2021). On the other hand, the multi-layer IoT applications will be deployed to achieve the most effective balance between cost-savings and flexibility (Guo, 2021). Cyber- physical system (CPS) is another Industry 4.0 tools technologies that can integrated with IoT application to control and monitor the environment and physical things. Also, cyber-medicine system (CMS) as a significant field of Cyber-physical system can be conducted in the management of the healthcare system through the integration of medical facilities (Li, 2020; Mahesar, 2021; Rau, 2020).

2.10 Integration of BIM and IoT

Building information modelling (BIM) represents an advanced technology that facilitates the improvement of project delivery methods (Waidyasekara, 2021). The BIM project delivery, when thoroughly managedand developed, provides geometrically detailed, high fidelity, and distinctive component data sets as well as an extensive amount of operable and descriptive information (Jung, 2021; Li, 2020).

According to Sun (2021) IoT will be identified as the connection of actuating and sensing devices that can provide the ability to share data and information across platforms of innovative applications. The digital technologies that can use the IoT for sharing data are including data processing solutions, software and cloud platforms, software and algorithms, identification technologies, security mechanisms, communication networks, sensing technologies, hardware, power storage, position technologies, and so on (Wang, 2021)

Furthermore, the integration of BIM and IoT connection is considered as a relatively new development (Babalola, 2021). According to Cheng (2020) the combination of the IoT and BIM application can complement the views of the construction project digitally and supplement the limitations of each. Actually, BIM models by incorporating geometry and offering high fidelity representations of the construction project attempts to provide a high-fidelity operable dataset that capture the designed building objects. On the other hand, IoT data can enhance the digital information by providing the recordable status of the operation in the construction project. (Elghaish, 2021; Guo, 2021).

In addition, IoT data and BIM will be accessed through several mechanisms that are including database connections to the systems, manual interfaces of proprietary systems, export via open standard, and programming APIs that associated with these applications (Dave, 2018). So, several number of open standards can be emerged in both IoT andBIM area. Also, he claimed that BIM and IoT devices can be conducted in several aspects such as health and safety management, energy management, building management, and construction monitoring as follows (Waidyasekara, 2021; Jung, 2021; Liu,2022).

On-site real time control and monitoring- By considering the on-site real time monitoring, BIM and sensors will be used for real-time site visualization and control through Virtual Reality (VR) tools. Other benefits of the integration of the BIM and IoT can be to control the equipment operation automatically (Li, 2020). Also, real-time sensory by capturing realistic environmental conditionsthat incorporated with BIM tools, and devices can calculate the automatic crane operations, compactor's path, and equipment operator's instruction (Papadonikolaki, 2022).

Health & Safety monitoring- According to (Jung, 2021), incorporation of the sensor devices and BIM can used for the safety matters to achieve visualization and notification, risk identification, and real-time data query over BIM tools and models to avoid risk in confine- spaced and complex construction projects. Also, in order to accomplish health monitoring, toolsand application such as RFID tags, BIM models, and monitoring sensors enable the ability to examine a malfunctioning component (Sun, 2021; Waidyasekara, 2020).

Operation and Building maintenance- IoT devices integrated with BIM will make various benefits and drivers for assisting operation and maintenance practices such as checking maintainability, updating digital assets management, and accessing the real-time data (Waidyasekara, 2020). Also, building operation and maintenance can be used for various aspects of the smart construction site including linking digital objects with physical objects by using BIM tools, recognising physical building components and linking with BIM models through RFID tags for asset tracking,and extracting real-time data to control or maintenance of the assets (Wang, 2021; Babalola, 2021).

Early disaster management- Numerous types of sensors and BIMtools will be the effective tools in recognizing the early disaster management particularly at theurban and building scale (Babalola, 2021). Following the emergency response, IoT devices and BIM will be utilized for areas including as development of mobile evacuation instructions, Identifying the location of the victims who are entrapped, large scaled emergency response utilizing GIS, and using location data and real-time data from mobile devices to determine the fastest evacuationroute (Cheng, 2020; Elghaish, 2021).

Resource control and monitoring- Following the resource control and monitoring, sensors like motion sensors and bluetooth sensors will be utilised to track and monitor the movement of equipment and labors in the site projects (Elghaish, 2021). Also, these tracking systems can be integrated with the BIM tools to visualize the moving paths (Tanga, 2019).

Automation in prefabrication- Integration of the BIM tools and advanced sensor technologies can help the operation and project managers to facilitate automation in prefabrication (Oesterreich, 2021). Incorporating the IoT application such as RFID tags with the BIM models will be the effective tools and technologies for prefabricated manufacturing visualization, tracking, and logistic withautomatic assembly (Guo, 2021; Babalola, 2021).

2.11 Drivers and Challenges of Implementing IoT

Following the rapid appearance of technologies such as the fourth revolution of the industry particularly in the construction and manufacturing industries, it is significant to recognise the main drivers and challenges of implementing the IoT in the construction industry (Xuc, 2018). So, some of the common drivers of implementing IoT in the manufacturingand construction industries are include the power consumption, security, and privacy requirements for conducting IoT software and hardware applications (Panteli, 2021; Carpio, 2021; Guo, 2021).

Also, Muller (2017) claimed that the quality of service (QoS) and safety will be the key limitation of using IoT applications in the construction environment. He and other authors discussed the other common challenges in implementing IoT application in the construction industry including adaptability, portability, connectivity, resiliency, maintainability, service availability scalability of IoT devices and applications (Rau, 2020; Mahesar, 2021; Guo, 2021). Following the literature, the significant drivers and barriers for implementing theInternet of Things (IoT) application in the construction industry are as follows:

2.11.1 Benefits of implementing IoT

Following sections will be discussed the crucial benefits of IoT applications implementation in the construction industry including:

Cost savings

Labour costs are reduced when labor-intensive operations are mechanised, such as through the utilisation of robots or automated workflows. As a further advantage, integrating embedded sensors to automate the tracking of equipment and materials could lower the cost of materials (Haghighi, 2020).

Time savings

Additive manufacturing and Prefabrication are two prominent instances of cutting-edge manufacturing techniques that make it possible to construct buildings and infrastructure more quickly than using traditional construction techniques (Kim, 2021).

Delivery time

It has been demonstrated in the past that it was difficult to deliver construction projects on time and within budget. The implementation of BIM in construction projects could aid in reducing project delivery times while keeping projects under the budget (Guo, 2021).

Improving quality

Since mistakes and errors could possibly be eliminated in the early stages by modelling every phase of the construction process, it has been proposed that adopting BIM simulation technologies such as BIM could improve the building's quality. Additionally, project managers can employ Big Data analytics to assist them make more sensible decisions based on historicalinformation and data (Ruan, 2021).

Collaboration and communication enhancement

Each construction project involves a large number of participants, therefore cloud-based applications and BIM advanced tools could substantially boost communication and collaboration through the construction projects participants (Kim, 2021).

Client relationship improvement

Construction businesses possess the ability to present project owners with greater accurate information and design insight into a building before it is constructed through the utilisation of simulation technologies like Virtual Reality and Augmented reality (Tezel, 2021). Clients can therefore participate in the planning stage of the project for better construction customization.

Safety enhancement

The substantial number of papers on safety management demonstrates that one of the most crucial concerns in construction projects is safety (Ruan, 2021). The construction industry is widely recognised for experiencing an elevated rate of work-related injuries and accidents due to its hazardous and risky working environment. Therefore, a variety of strategies have been set forthby academics and professionals to enhance construction safety, such as utilising wearable digital devices like Smart Helmets and Smart Glasses, virtual safety training programs, and employing risk plans to prevent work accidents (Carpio, 2021).

Improving the image of the industry

Construction companies are widely recognised for their harsh workplace environment and low levels of digitalization (Haghighi, 2020). As a result, it has a negative employer reputation, frequently has troubleattracting highly talented, qualified, and skilled applicants. The construction industry's image could potentially be enhanced through the digital transformation of the entire sector (Panteli, 2021).

Sustainability improvement

The construction industry produces considerable quantities of carbon dioxide emissions due to its high energy consumption and waste production during construction development. Several strategies have been proposed to address these environmental issues, including minimizing construction waste by implementing the strategic project management and adopting BIM technology to provide advance design alternatives (Guo, 2021; Mahesar, 2021).

2.11.2 Challenges of implementing IoT

Following sections will be discussed the crucial challenges of IoT applications implementation in the construction industry including:

Hesitation to adopt

Construction businesses are reluctant to make investments in advanced tools and technologies because of their high investment costs and ambiguous benefits (Jung, 2021). Thus, encouraging constructionbusinesses to adopt initiative tools and technologies is one of the key concerns. This could be accomplished, for instance, by presenting incentives for adoption, through financing programmes for industry, research, and government (Mahesar, 2021; Rau, 2020; Kang, 2022).

High cost of the implementation

Digital technology adoption in the construction industry is hampered by the high cost of technological devices, training, and education, as well as external consulting costs (Kang, 2022). Further, unresolved issues include unclear benefits, inaccurate cost-savings predictions, and a lack of financial benchmarking that is sufficient to impact negatively for construction company's gainsand improvements (Ahankoob, 2021). In this instance, the innovation of methods and devices for optimising andevaluating costs and benefits as well as the establishment of partnerships amongst industry associations could aid in enhancing transparency and minimising cost (Craveiro, 2021).

Organisational and process changes

All organisational levels are required to implement cutting-edge tools and technologies, which principally necessitates re-engineering and re-evaluating current construction company's processes (Jung, 2021). The primary issue facing construction organisations is how to effectively manage internal organisational and process changes while redesigning their existing business model (Li, 2021).

Enhanced skills are required

A particular level of knowledge will be required in order to utilise cutting-edge technology (Oesterreich, 2021). There will be an increasing requirement for personnel training, development, and integrationskills due to the low technical proficiency of construction employees on site. Therefore, the primary challenge is to develop and establish new capabilities to improve the construction project's framework, and attract talented professionals, such as hiring skilled personnel that have a shared knowledge of technology and experience as a top selection criterion (Haghighi, 2020). Construction companies should additionally motivate their staff to work together and shareideas in order to create innovation. This will open possibilities for multidisciplinary teams towork together to optimise performance (Panteli, 2021).

Knowledge management

Because of the fragmented and temporary nature of the construction projects, that there are few standards for knowledge management and shared project information (Ruan, 2021). The biggest obstacle is developing and implementing knowledge management standards throughout the organisation. This could be accomplished by automated data collection, integration into projecthistory, and the capture and reuse of project knowledge (Guo, 2021).

Acceptance

Other significant characteristics of the construction industry could be resistance to change to adopt the new tools and technologies, conservatism, and lack of adaptability expressed by its employees (Li, 2020). The potential loss of jobs due to the use of robots, computers, or other automatedsystems is another significant concern for employees over the adoption of innovative technology (Ruan, 2021). So, as acceptance is a crucial success component for the adoption of new tools andtechnologies in the construction industry, communication and change management are required to assist employees in adapting. Therefore, in order to provide employees an awareness of ownership over the enhancement of performance, construction businesses couldutilise "opinion leaders" as change agents throughout the implementation phase of the construction projects (Panteli, 2021; Kim, 2021).

Lack of regulations and standards

Although most digital technologies are already developed and widely accessible, many of them actually lack the appropriate standards (Ruan, 2021). For instance, there is no comprehensive standard for RFID technologies, readers, BIM standards, or multi-protocol tags, which results in software incompatibility (Kim, 2021). In addition, Industry 4.0 requires a reference architecture, designed to meet the requirements of the industry. This reference architecture will be developed with particularemphasis on its structure in considering the unique environment of the construction industry (Li, 2020).

Computing equipment requirements

As environmental factors like traffic and weather have a significant impact on construction projects, there are higher specifications for the operation of the computing equipment required in the construction site environment (Papadonikolaki, 2022). Advanced Mobile devices, for instance, should be designed to control and monitor the humidity, severe vibration, and large falls (Dave, 2018).

Data protection and data security

The necessity for data protection and data security is developing as a result of the increasing data and information volumes, collaboration and exchanging information with external partners, and increasing requirements for mobility (Waidyasekara, 2020). So, employing centralised cloud-based system, data security technologies, control the accessibility, and device management could helpconstruction businesses protect their information and data against any other type of misuse (Babalola, 2021).

Communication networks improvement

On construction sites, fast, consistent, and reliable Internet connectivity is crucial for the effective utilisation of communication and information technology. As a result, one of the biggest challenges to be addressed has been described as inconsistent internet broadband connectivity for collaborative applications (Kamblea, 2018; Elghaish, 2021; Haghighi, 2020)

Regulatory compliance

The automatic capturing and recording of personal data are necessary for the effective utilisation of RFID technology for workforce and safety management (Haghighi, 2020). The monitoring and tracking of staff members as well as the processing of the recorded data and information usually raise ethical and legal issues in different construction site environments (Panteli, 2021). For instance, outsourcing corporate data including personal information regarding businesses or employee outside the European Economic Area is subject to rigorous regulations under German data protection law and regulation. So, prior to employing these technologies, restrictions associated with privacy and data protection must be reviewed by engaging legal advisors fromthe initial stages of the construction process (Ruan, 2021).

Contractual and legal uncertainty

Uncertainty in the law and in contracts regarding the utilisation of BIM is a further obstacle (Guo, 2021). Forinstance, the issues of model ownership for errors and issues with the model should be resolved (Carpio, 2021). By considering these drivers and challenges, this research seeks to develop a framework for implementing the Internet of Things (IoT) application in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT adoption in the construction industry.

2.12 AI and Construction Industry

An extensive review of artificial intelligence (AI) and how it is employed in the construction industry will be discussed in this section. The author will explore how AI and IoT can be leveraged to drive productivity gains, enhance construction project management, and improve overall performance. Additionally, I will delve into the benefits and challenges applied with the integration of these cutting-edge technologies in the construction industry.

2.12.1 What is AI

Artificial intelligence, or AI, is the term used to describe how computer systems, can simulate human intelligence processes. This covers verbal comprehension, learning, thinking, and problem-solving (QJ, 2020).

Artificial intelligence (AI) is permeating every aspect of our lives, from self-driving cars to personalised streaming service suggestions to virtual assistants (Salgado, 2021). By building computers that are capable of activities that traditionally require human intelligence, artificial intelligence (AI) hopes to increase production and efficiency across a range of industries and sectors (Salgado, 2021).

AI has the ability to completely transform the construction sector by optimising workflows, boosting productivity, and enhancing security. With AI-powered tools such as drones, robots, and predictive analytics, construction companies can optimize project planning, reduce errors, and enhance productivity (Xiong, 2021). Additionally, AI can help in monitoring and managing equipment maintenance schedules, predicting potential hazards on job sites, and even assisting in design and engineering tasks. Therefore, the use of artificial intelligence (AI) in the construction sector has the capacity to stimulate creativity and revolutionise the processes involved in project planning and implementation (Tam, 2022).

2.12.2 Benefits of using AI in the construction industry

Following sections will be discussed the crucial benefits of AI implementation inthe construction industry including:

Project Planning and Scheduling

By utilizing AI technology, construction companies can optimize their project schedules, identify potential risks and delays, and make more informed decisions throughout the project lifecycle (Sepasgozar, 2021). Large volumes of data may be analysed by AI systems to predict project results, recommend optimal scheduling strategies, and even automate certain tasks to improve efficiency and productivity. With AI in Construction, project managers can have greater visibility into their projects, leading to better planning, resource allocation, and ultimately successful project delivery (QJ, 2020).

Automated Site Monitoring and Quality Control

With the use of AI-powered drones and sensors, construction companies can gather real-time data on project progress, safety compliance, and quality assurance (Xiong, 2021). With the use of this technology, possible problems may be found before they become more serious, thus saving time and money (Qian, 2022).

By utilizing AI for site monitoring, construction companies can improve efficiency, accuracy, and overall project management. Efficient and precise analysis of vast volumes of data facilitates improved resource allocation and decision-making. AI may also assist in seeing patterns and trends that human workers might not notice right away, resulting in more proactive problem-solving (Salgado, 2022). Another area in which AI may have a considerable impact on construction is quality control. By using machine learning algorithms to analyze data from sensors and cameras on-site, companies can ensure that materials are being used correctly, work is being done according to specifications, and safety protocols are being followed. This level of automation can help prevent costly mistakes and delays (Tam, 2022).

Predictive Maintenance and Asset Management

Predictive maintenance and asset management are two key areas where AI can revolutionize the construction industry (Tezel, 2020). Construction companies can help save time and money by anticipating when maintenance is required before a breakdown happens by using AI algorithms to analyse data from equipment and sensors (Xiong, 2021). Additionally, AI can help optimize asset management by tracking the performance of equipment and recommending the best course of action for maximizing efficiency and reducing downtime. So, incorporating AI into these processes can lead to improved productivity, cost savings, and ultimately better outcomes for construction projects (Sepasgozar, 2021).

Procurement and Supply Chain Optimization

By leveraging AI technology, construction companies can streamline their procurement processes, improve supplier management, and enhance overall supply chain efficiency (Tezel, 2020). The ability of AI to quickly and precisely analyse large volumes of data is one of the main advantages of employing it in procurement. This could assist construction businesses in choosing suppliers, negotiating contracts, and controlling levels of inventory with greater insight. AI could assist with automating routine tasks like invoice matching and order processing, giving procurement professionals extra time to concentrate on strategic objectives (Xiong, 2021). In terms of supply chain optimization, AI can help construction companies predict demand fluctuations, identify potential bottlenecks in the supply chain, and optimize transportation routes (Qian, 2022).

By using AI-powered algorithms to analyze historical data and real-time information, companies can make better decisions about inventory levels, production schedules, and distribution strategies.In summary, Cost reductions, increased operational effectiveness, and enhanced supplier engagement are all possible outcomes of incorporating AI into supply chain management and procurement procedures (QJ,2020).

Automated Design and Engineering

By utilizing AI algorithms, architects and engineers can automate the design process, allowing for faster and more efficient creation of building plans (Xiong, 2021). This not only saves time and money, but also enables designers to explore more creative and innovative solutions (Salgado, 2022). By evaluating data and seeing possible problems before they happen, AI may also aid in the optimisation of the engineering process. This proactive approach can lead to better quality construction projects that are completed on time and within budget (Sepasgozar, 2021).

AI integration in engineering and construction has the ability to increase productivity, stimulate innovation, and simplify procedures. We might expect even more developments in automated engineering and design in the construction industry as technology progresses (Tam, 2022).

2.12.3 Challenges in implementing AI in the construction industry

Although there are many potential advantages of AI in the construction industry, their successful adoption will also require addressing a number of issues and concerns as follows:

Data Integration and Interoperability

The problem of data integration and interoperability is one of the main obstacles to employing

AI in the construction business (Tam, 2022). Construction projects involve a vast amount of data from various sources such as design plans, material specifications, scheduling information, and more. Effective integration and analysis of this data is challenging since it is frequently fragmented across several systems and formats (QJ, 2020).

AI technologies require access to high-quality and standardized data in order to provide accurate insights and predictions. Without proper integration and interoperability between different systems, AI algorithms may struggle to make sense of the disparate data sources, leading to inaccurate or incomplete results (Salgado, 2022). Construction organisations need to make investments in reliable data management systems that may standardise and centralise their project data in order to overcome this challenge (Sepasgozar, 2021).

They also need to prioritize collaboration and communication between different stakeholders involved in the project to ensure that all relevant information is shared effectively (Tam, 2022). By overcoming the obstacles related to data integration and interoperability, construction companies can unlock the full potential of AI technologies to improve decision-making, productivity, profitability, and efficiency (QJ, 2020).

Cybersecurity and Data Privacy

A significant obstacle to implementing AI in the construction sector is guaranteeing cybersecurity and privacy of data (Parn, 2021). As AI systems become more integrated into construction processes, they will be handling large amounts of sensitive data, including personal details of employees and clients, financial information, and project plans (QJ, 2020). This data is vulnerable to cyber-attacks and breaches, which can have serious consequences for both the construction companies and their clients. It is crucial for companies to invest in robust cybersecurity measures to protect their AI systems and the data they handle (Qian, 2022). Additionally, there are concerns about how AI systems in construction may infringe on individuals' privacy rights. For example, AI-powered surveillance systems used on construction sites may inadvertently capture personal information or violate workers' privacy rights (Salgado, 2022).

Companies must be mindful of these risks and ensure that their AI systems are designed and implemented in a way that respects data privacy laws and regulations (Sepasgozar, 2021).

Therefore, addressing cybersecurity and data privacy challenges will be essential for the successful integration of AI in the construction industry.

Workforce Upskilling and Change Management

One of the primary obstacles to deploying artificial intelligence in the construction sector is the requirement for change management and employee upskilling (Tezel, 2020). Many workers may be resistant to adopting new technologies, fearing that they will be replaced by machines. To assist staff members, acquire the skills required to collaborate with AI systems, businesses have to support training programmes (Tam, 2022).

Additionally, change management is essential to ensure a smooth transition to AI-powered processes (Sepasgozar, 2021). Companies must communicate effectively with their employees about the benefits of AI and involve them in the decision-making process. Resistance to change can hinder the successful implementation of AI in construction projects, so it is significant for construction companies to assess and address any concerns and provide support throughout the transition (Qian, 2022).

Therefore, workforce upskilling and change management are key factors in overcoming the challenges of using AI in the construction industry (Xiong, 2021). By investing in training programs and effective communication strategies, companies can ensure that their employees are prepared for the future of work and can fully leverage the benefits of AI technology (Sepasgozar, 2021).

Cost and Return on Investment (ROI)

The initial costs associated with using AI technology provide an important barrier for the construction industry. The upfront investment required to integrate AI systems into existing construction processes can be significant, especially for smaller companies with limited resources. Moreover, the training of staff members for using and maintaining AI systems could result in ongoing expenses (Qian, 2022).

Another challenge is determining the return on investment (ROI) of implementing AI in construction. While AI has the potential to improve efficiency and productivity on construction sites, it can be difficult to quantify these benefits in terms of financial returns (Xiong, 2021).

Companies may struggle to accurately measure the impact of AI on their bottom line, making it challenging to justify the initial investment in AI technology (Tam, 2022). To overcome these challenges, construction companies should carefully evaluate their specific needs and goals before investing in AI technology. They should also consider partnering with experienced vendors who can provide guidance on how to effectively implement and measure the ROI of AI solutions in their operations (Salgado, 2022).

2.12.4 Integration of AI and IoT in the construction industry

The planning, executing, and monitoring of construction projects could be completely transformed by implementing AI and IoT applications (Tezel, 2020). Project managers may examine enormous volumes of data using AI-powered tools to improve timelines, uncover possible dangers before they become serious, and make better decisions (Sepasgozar, 2021). IoT devices, such as sensors and drones, could allow team members better communication and preventative maintenance by providing real-time information on equipment performance, worker safety, and job site conditions (QJ, 2020). Furthermore, the use of AI and IoT in the construction industry could result to significant cost savings by reducing waste, improving resource allocation, and minimizing downtime (Salgado, 2022).

By harnessing the power of these technologies, construction firms can not only increase their competitive edge but also contribute to a more sustainable and efficient industry overall (Tam,2022). As AI and IoT continue to evolve and become more accessible to construction companies of all sizes, it is clear that embracing these innovations is no longer optional but essential for staying ahead in an increasingly digital world. The future of construction lies in smart technologies that enable smarter decision-making, better collaboration (QJ, 2020). Actually, the integration of AI and IoT in the construction industry holds immense promise, offering the potential to drive significant productivity gains, enhance project performance, and improve overall operational efficiency (Parn,2021). By leveraging these advanced technologies, construction firms can streamline planning and scheduling, automate site monitoring and quality control, optimize asset management, and enhance supply chain operations (Sepasgozar, 2021).

However, the successful implementation of AI and IoT in construction will require a holistic approach that addresses data integration, cybersecurity, workforce upskilling, and the careful evaluation of costs and expected returns (Qian, 2022). By proactively addressing these challenges and embracing the transformative potential of these technologies, construction firms could position themselves for long-term success and maintain a competitive edge in an increasingly dynamic and technology-driven industry (Salgado, 2022).

2.13 Summary

This chapter discussed a literature review on the construction sector, digital transformation, Industry 4.0 technologies, Building Information Modelling (BIM), Internet of Things (IoT), and evaluates the impacts of these technologies in the UK construction industry.

The UK construction industry as a significant part of the UK economy has been always criticised for being fragmented, having failed attempts to deliver projects on time and under budget for the last five decades. For this reason, advanced technology referred to as “Smart Construction” is increasingly being used in the construction industry to increase decision-making and improve productivity. Actually, smart construction by employing construction resources such as devices, components, machinery, and people aimed to transform digital technologies in the construction industry.

So, for implementing smart construction by utilizing digital tools and techniques, Industry 4.0 or the fourth industrial revolution has been created to convert the construction industry in the direction of further digitally developed trades. Following Industry 4.0 and digital transformation concepts, numerous aspects of the construction phase have changed as a result of Industry 4.0 technologies such as Internet of Things (IoT), Cloud-computing, Cyber-physical systems, Automation, 3D printing, Robotics, and so on. Internet of things (IoT) as a crucial part of the industry 4.0 technologies has a significant role in advancing the possibilities of smart construction concepts in a variety of construction phases.

This research seeks to evaluate the role of the internet of things (IoT) in enhancing the performance of the UK construction industry. Furthermore, in terms of modern construction methods such as smart assembly, offsite construction, and lean philosophy, this research seeks to develop the framework, presents the applications of IoT, and identifies the emerging benefits and drawbacks of IoT applications in the UK construction sector.

Chapter 3. Research Methodology

This chapter outlines the research methodology utilised to investigate the research questions regarding the impacts of Internet of Things (IoT) implementation in the construction industry, addressing the research process, methods, and strategies.

3.1 Research purpose and definition

It is crucial to determine the study goal and its primary focus before outlining the research approach and methodology (Creswell et al, 2009). According to Neuman (2003) research is identified as the process of investigating and developing an inquiry about an experience or occurrence to generate and develop ideas, strategies, and solutions on a particular status or topic (Neuman, 2003).

Research can be answered and addressed the questions of how, why, and what and has several interpretations. Research has several significant aims and purposes: to predict, to describe, to assess, or to evaluate to impacts (Beiske, 2007). The key purpose of this study is to develop a framework for implementation of the Internet of Things (IoT) application in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT adoption in the construction industry. So, Due to the establish of the effective development of the research methodology, as seen in figure 5 each layer of the study could represent the detailed stage of the research process (Saunders et al., 2012).

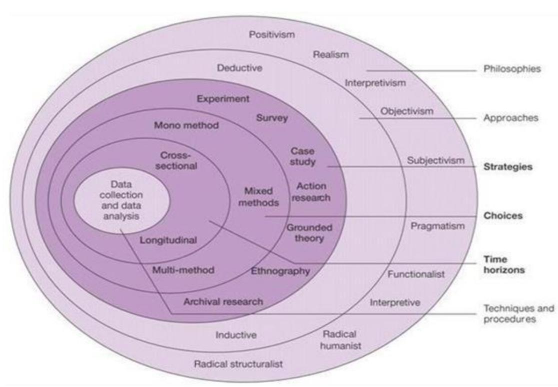


Figure 5 Research Onion.

3.2 Research philosophy and approaches

All research studies are created to address and answer the problems which shaped in the real world. Research methodology is a procedural framework and refers to logical thought processes and principles that can be applied for a scientific investigation. For investigating the research problems, effective application of methodological techniques has a key role to successof the academic research (Beiske, 2007; Bryman, 2008).

Based on the research process, research philosophy is the route and term that utilized to communicate the nature of the knowledge and development of the knowledge (Saunders et al, 2012). For adopting a philosophical view point, there is significant discussion around quantitative and qualitative methods or between interpretivist and positivist research philosophy. Although, in recent times adopting a multi-dimensional set of continua is one of thesolutions that has been suggested to have a great research philosophy than as distinct positions. So, the importance of the research's philosophical approaches cannot be overstated, since the concept of the study's findings will be negatively impacted if philosophical concerns are not acknowledged (Creswell et al, 2009).

At an early stage of the research study, considering understanding and thinking about philosophical approaches can be able to assist in gathering and analysing the kinds of data needed to answer the research question. Also, research philosophies can assist researchers in addressing the research questions by creating research designs through the research project based on their experience and knowledge. In addition, in order to accomplish the research's objectives, there is a direct link between the suitable approach and successful examples of scientific investigation. Actually, consideration of vigorous research philosophies can enable the researchers to understand scientific information and knowledge properly, and as a result, improve the quality of the research's accuracy (Creswell et al, 2009).

Dumay (2011) claimed that the research philosophy comprises of a theoretical perspective including epistemology and ontology. Also, it can be argued that the epistemology and ontology are the foundations of the research structure upon which the research is built. So, the methodology of the research will be determined by the researcher's epistemological and ontological assumptions (Dumay, 2011).

3.2.1 Ontological position

Ontology's primary goal is to provide a perspective on the nature of reality, in addition to what is relevant to the real world and its characteristics. Furthermore, ontological assumptions as a way of constructing reality by holding a various range of viewpoints of social realities could be positioned within historical, political, and cultural contexts to illustrate the differences (Dumay, 2011).

Saunders et al. (2012) claimed that the two significant pillars of ontology are namely the objectivism and subjectivism that will be identified as poles of a continuum. Objectivism argues “the position that social entities exist in reality to, and independent from social actors". So, based on this viewpoint, the elements will be subjected to a quantitative analysis. On the other hand, Subjectivism adopts actions and perceptions of the social actors that create the results in the constant state of change in the social phenomena. Social constructionism helps to understand the data and details of what is happening as an outcome of this interaction. Most researchers employ stances between these two principals including subjectivism and objectivism that importantly depends on research aims and objectives (Saunders et al.,2012)

3.2.2 Epistemology

The definition of epistemology is the philosophy of knowledge regarding its scope, validity, and relationship between belief and opinion. Also, in a particular field of study, it highlights the fundamental approach of understanding and evaluating the theory of knowledge and research philosophy. Epistemology has three main perspectives including “Positivism”, “Realism” and “Interpretivism” (Dumay, 2011).

The key principle of positivism is that genuine "factual" knowledge can only be attained by observation. Actually, in positivism research, the research findings are quantifiable and observable and data collection to test hypothetical deductive generalisations. It collects data and suggests a natural scientist's perspective on an observable reality, exploring for casual relationships and regularities to create deductive generalisations. Realism research philosophy is another Epistemology's perspective proposes to scientific investigation that idea of the objectivity of reality have an existence independent of the human mind. This philosophy can be divided into two pillars including direct and critical. Direct realism will be identified as portrays the world through personal human senses. On the other hand, critical realism claims that images of the real world can be deceptive and confirm that real structures exist independently of events or patterns (Fellows & Liu, 2008).

As a branch of epistemology, Interpretivism integrates the practice of naturalistic and qualitative approaches to inductively describe and understand a social phenomenon. So, based on this research philosophy, researchers argued that access to reality is just through social construction such as instruments, shared meanings, and language. Interpretivism is also described to increase the overall understanding of the subject of the philosophical position of idealism including phenomenology, hermeneutics, and social constructivism.

So, this approach leads the researcher to appreciate differences between people (Goddard, 2004). According to Saunders et al. (2012), Symbolic interactionism and Phenomenology are the two major parts of Interpretivism philosophy. Phenomenology is considered to the relationship between the area and phenomena in which this is a reality. It analyses phenomena and fact thrown into consciousness which are advocated by the positivist philosophy. On the other hand, interacting in a continuous process of understanding other people's behaviors, whichthen influences how we adjust our own actions, is defined as symbolic interactionism. (Saunders et al., 2012).

3.2.3 Pragmatism

Following the research philosophical choice, researchers usually debate between ontology and epistemology (Johnston, 2014). Nevertheless, Saunders et al. (2012) argued that the research philosophy positions adopted in any study should be seen as a continuum rather than opposing thoughts. According to Saunders et al. (2012), the research question is the most significant determinant of the research philosophy that can be worked with both philosophies.
Pragmatism enables the researcher to utilise empirical techniques and methods and also share strong links with constructivism. In addition, a pragmatic research philosophy will be identified

as the “singular” and “multiple” realities that solve the practical problems in the real world (Saunders et al., 2012).

3.2.4 Philosophical approach adopted by this research

The research methodological procedures explain how the research methods shall be selected. Also, it justifies reasons on why they have been selected and fit well within the conducted research, which is referred as research methods design (Saunders et al., 2012).

Research philosophy is one of the vital parts of the research methodology process that will be identifies as a fundamental and basic concepts and paradigm to understand the specific area ofa study. Also, in order to appropriately engage with a setting to analyse and discover the boundaries for research assumptions, the researcher will be required to understand assured philosophical conceptions (Naoum, 2013). According to Naoum (2013), understanding philosophical assumptions will be essential for any research to gain and achieve the valid knowledge.

So, making a good philosophical assumption at the fundamental step of the research will provide an opportunity for researcher to consider and select the research methodology properly. Following the research philosophy paradigm, a pragmatic research philosophy is adopted in this research study to address the practical problems and issues in the real world (Naoum 2013). The purpose of this research is to develop a framework for implementing the Internet of Things (IoT) application in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT adoption in the construction industry. So, the research philosophy paradigm adopted in this study is a pragmatic assumption that utilizing both interpretivism and positivism paradigm.

Pragmatism by considering the middle view of both assumptions (interpretivism and positivism) can enable the researcher to be free from the practical restrictions to the choice of constructionism or positivism views to answer and address the research questions. Neuman (2003) stated that all social knowledge is gained based on experiences. It means that the knowledge is socially shared because it comes from socially shared experiences. So, in relation to the research environment, Newman (1998) claimed that the construction and project management field as a multidisciplinary research study should adopt the pragmatism approach which works best for the specific research issues to meet the aim and objectives.

In addition, pragmatism paradigm by utilizing two perspective including positivism that identify the prospective viewpoints of practitioners and interpretivism that focus on making more sense of the world should adopt in this research to obtain the realities of the construction management objectives (Newman, 1998). Also, the other pivotal features of the pragmatisim approach is that the researcher can apply mixed methodology including quantitative and qualitative research methodologies to design the research study (Beiske, 2007).

The researcher adopts the pragmatism approach to explore and discover the research questions to meet the aim and objectives that are set out for this research. Following the interpretivism approach, qualitative data collected through semi-structured interviews from participants involved in the digital transforming the construction projects in the UK. Therefore, pragmatism is adopted as a philosophical stance for this research.

3.3 Research approach

One of the significant characteristics of research design is the approach to reasoning that it incorporates. Beiske, (2007) claimed that the research approach is identified as how theory is established in social science. Also, in order to design the research approach, Creswell (2009) argued that the connection between empirical phenomena, method, and theory are anchored to three principal reasoning approaches that will be namely as “deductive”, “inductive”, or “abductive” (Creswell, 2009).

The deductive research approach can be identified to develop a theory and design a research strategy to test the hypothesis. The inductive approach, on the other hand, the researchers collects data and information and develop hypothesis as a result of data analysis. Dumay (2011) argues that an inductive research is close to interpretivism and deductive approach is close to positivism (Dumay, 2011). Each research approach by considering the theory, empirical phenomena and methods will be explained in the following subsections.

3.3.1 Deductive research approach

The progress of a theory or hypothesis that is tested by empirical observation is referred to as the deductive method. The method described above relies on hypothesis testing could be applied for an objectivist ontology and explaining what questions in the natural sciences. One of the significant features of deductive research will be the early development of the theory that leads to test of a theoretical proposition through empirical research using quantitative data which is help to validate the hypotheses or theories when the process is repeated (Dumay, 2011).

Furthermore, Fellows and Liu (2008) claimed that the deductive approach can be called a top-down methodology which works from the broader to the particular theory. Following this approach, the first step is to identify a hypothesis and then narrowed down into a more specific theory that will be assessed before narrowing down further by collecting observations to solve the problem. The final step is test of the theories and hypotheses with particular data and information that helps to confirm the original theory. So, deduction of conclusions from propositions or premises or is the primary objective of the deductive approach, shown in figure6 as (Guba & Lincoln, 2005):

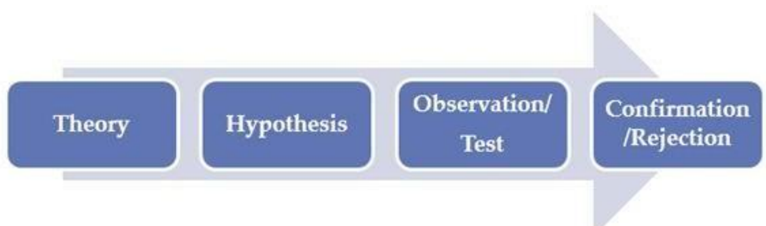


Figure 6 The Deductive Approach

3.3.2 Inductive research approach

The inductive approach is also identified as a base up approach to promote the development ofa hypothesis and it goes from the particular to the general. Actually, it is implemented to explore a phenomenon to formulate theory and create a conceptual framework. In comparison to the deductive reasoning, it develops a theory from observations or empirical facts as to testing a theory. Induction is the converse of deduction, observations are contemplated inside the setting of the fact and phenomenon that leads to formulate of the concepts to understand and explain the observation. Subjectivist ontology generally employs an inductive approach as amethod of addressing certain concerns (Fellows and Liu, 2008).

Trochim and Donnelly (2001) claimed that inductive research approaches are established by moving from specific observations to broader theories and generalisations. For that reason, the process begins with specific measures that the researcher starts to notice regularities and formulates hypotheses to emerge some general theories or conclusions. So, inductive research approach is more open-ended, while deductive research approach is generally utilised to confirm or test hypotheses, can be seen in the figure 7(Guba & Lincoln, 2005):

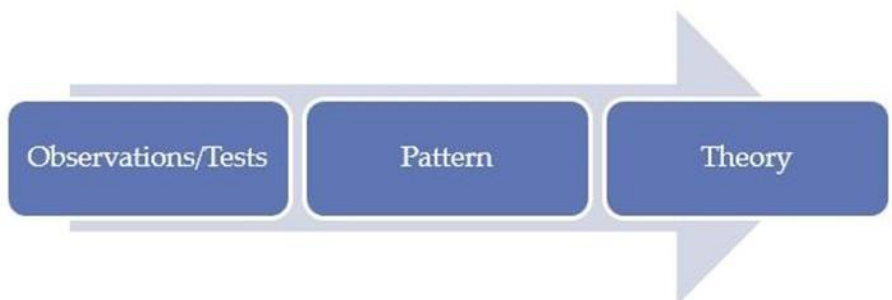


Figure 7 The Inductive Approach

3.3.3 Abductive research approach

Fellows and Liu (2008) claimed that the abductive research approach is more complex than both deductive and inductive that it provides reasons rather than causes to answer both why and what questions. Also, the abductive research approach will be intuitive, creative, and even revolutionary and it differs a theoretical understanding informed by people, context, meanings, and language. Therefore, combining inductive and deductive research approach moves back and forth that may lead to a greater and more important outcome. According to Goddard (2004), in modern science, the abductive research technique has been adopted by a number ofdisciplines, each of which has further developed it. The numerous disciplines which are adopting abductive research approach range from logic, linguistics, artificial intelligence, neuralnetworks, learning, and so forth (Goddard, 2004).

So, when compared to using a strictly deductive or inductive approach, the abductive research approach produces more satisfying results. In terms of which approach to adopt, if issues have been identified in relation to choosing between induction and deduction, Goddard (2004) the research methodology that is really chosen should be the one that is most appropriate for the study questions. Although induction and deduction can be combined, abductive researchers are required to provide a clear description of the research process in order to assure the scientific reliability of the research technique in issue and allow other researchers to examine the study results (Goddard, 2004).

3.3.4 Research approach adopted by this research

By considering the three different forms of research approach (deductive, inductive, abductive) to support the research philosophy, this study adopted an inductive reasoning to develop a framework and understand the role of the internet of things (IoT) in enhancing the performance of the UK Construction industry.

According to Johnson and Onwuegbuzie (2007), one of the main characteristics of deductive research will be the early development of the theory from literature that leads to test of a theoretical proposition through empirical research using quantitative data which is help to validate the hypotheses or theories when the process is repeated. van Hoek et al. (2005) claimed that the abductive research approach is more complex than both deductive and inductive that it provides reasons rather than causes to answer and both why and what questions.

In this study, inductive reasoning was applied to enable the researcher to interplay between theory and empirical observation to generate the new theory (Johnson and Onwuegbuzie, (2007). Also, the inductive reasoning allows the researcher to develop framework that will be useful for stakeholders to adopt and understand the impact of the industry 4.0 technologies such as IoT application in the UK construction sector. This framework is generated by identifying the emerging themes, benefits, and drawbacks of IoT applications in the UK construction sector. So, by adopting the qualitative approach, the researcher can investigate and examine the theories from inductive perspectives.

3.4 Methodological Choice

According to Goddard (2004), The method of study can generate and construct a strategy on how to answer the research questions and gather the data and informationThe possible choices for the research approach include the "mono method," "mixed method," and "multi-method" based on the onion research strategy (Goddard, 2004).

Following the research methodology in research onion, the single research strategy for the study is referred to as the mono-method. The mixed-method refers to the use of both a quantitative and qualitative technique that generates a single dataset and involves utilising two or more methodologies for research. In the multi-method, as the names of these approach suggest, various selection of methods will be utilised which the research is divided into separatesections, each is then analysed using methods and techniques derived from qualitative or quantitative methodologies.

Quantitative approach can be described as one of the significant research methods that is used for an objectivist philosophy, focused on theoretical observation and evidence to confirm proposed theories. However, subjectivism which relies on non-numerical facts and information to support any given theory is implemented through qualitative research. In the following sections, each type of the research methods will be discussed (Creswell et al, 2009).

3.4.1 Qualitative research

Qualitative research can be described as social research to examine phenomena to gain collect and understanding information and data through views of participant’s perceptions. To study phenomena at this research method, the subject is undertaken without prior formulations that are not explained through indices and numbers. Also, form of social research termed a qualitative study emphasises on how individuals interpret and seeks to explore and understand groups or individual’s experiences, behavior, and attitudes (Creswell et al, 2009).

Beiske (2007) argued that qualitative research method identifies as a social reality created by the participants to develop a theory through visuals, meanings, and words. Qualitative studies tends to concentrate on a single case, unit, or subject examined via phenomenological perception and depends upon the researcher being a fundamental unit of the data gathering and deciphering the results in an enumerative way. According to Beiske (2007), significant characteristics of qualitative approach are as follows:

- Qualitative research methodology can provide in depth, rich, and extensive information.
- Close contact between the interviewer and interviewee can allow a greater freedom of expression for data collection.
- Samples will be selected in a small scale and based on people's opinion and perception.
- The process of the qualitative research methodology is open ended that allows the researcher to produce detailed descriptions and develop explanations.
- Reduced cost and time because of the possibility of using Internet interaction between the interviewer and interviewee due to prevent the time and distance constraints.
- Because of the small scale of samples, collection, monitoring, and analysing of the responses will be easier and faster.

Following the research methodology, qualitative study represents people's happenings, circumstances, and interactions that are observable. It relies on how individuals communicate their own experiences, ideas, and beliefs. The method of qualitative study doesn't depend on numerical data to establish its conclusions and may track improvements over timeBy providing a comprehensive theoretical explanation of the meaning of the information and facts that have been gathered, and by progressing from the specific to the general, a qualitative study's relationship to an inductive method is defined. Also, the primary aim of qualitative research is to translate, describe, decode, and understand the meaning of social phenomena as they occur. This is done by using a variety of interpretative approaches and tools. (Beiske, 2007).

A qualitative research method is linked with several strategies and each strategy has a specific procedures and rules. There are two types of qualitative research strategies including: Exploratory that can be appropriated to obtain additional particular dimensions to existing information or limited information and knowledge is available on a specific subject. On the other hand, Attitudinal is appropriate to use for the assessment of perceptions in relation to a particular subject matter. For analysing the data in a qualitative research method, the explanation of the phenomenon in the real world must be produced by a researcher.

Moreover,analysing data from the computer programmes in this research approach takes longer time than the quantitative research method to generate the efficient results (Dumay, 2011).

The main strengths and characteristics of the qualitative research method are including: (Goddard, 2004; Guba and Lincoln, 2005)

- This research method can gain realistic feel of the real world that will not be experienced in the numerical data utilized in quantitative research method.
- Flexibility to interpretation of collected data and information.
- The ability to produce, present a comprehensive understanding of the phenomenon, along with interacting with the study's subjects in their own words and languages.; and
- Last but not least, descriptive capability of the research project is founded on principal information.

The major disadvantages of the qualitative approach are including: (Goddard, 2004; Guba and Lincoln, 2005)

- Researcher should have a high level of experience to gain the targeted data and information from the respondent.
- Based on the same data and information, different conclusions could be reached depending on the personal characteristics of the researcher.
- Because of the manner in which the context is changing, it is challenging for a researcher to analyse the relationships between various research phenomena in accordance with the initially established objectives of the study.
- Lack of the reliability and consistency because the researcher will use various probing tools and techniques that the individual who responded will select particular explanations to present and reject others.

Here are some ways to overcome the disadvantages of using qualitative research methods in research:

One way to overcome the disadvantages of using qualitative research methods is to complement them with quantitative research methods (Merriam, 2016). By incorporating both qualitative and quantitative approaches, researchers can gain a more comprehensive understanding of the topic being studied. Additionally, researchers can also consider using mixed-methods research designs, which combine both qualitative and quantitative data collection and analysis techniques (Miles, 2014; Creswell, 2018)

In that case, initially, the researcher tried to use the mixed-methods by combining both qualitative and quantitative data collection that can help to validate findings and provide a more comprehensive understanding of the research topic on implementing IoT applications in the UK construction sector. However, after sending the online questionnaire to more than 100 project managers that working in the UK construction sector and receiving just %10 feedback from them, the researcher decided to just focus on the qualitative research method by interviewing from the project managers in the UK construction industry to collect the proper data for analysing to get the final results.

Another way to address the limitations of qualitative research is to ensure that the sample size is appropriate for the research question being investigated (Onwuegbuzie, 2007). By increasing the sample size, researchers can enhance the generalizability of their findings and reduce the risk of bias (Moors, 2000). In that case, researcher found that after getting the 38 interviews from several project manager in the UK construction industry, the data saturation is achieved. Creswell (2018) recommend 20 to 60 interviews could be suitable in this regard. In addition, according to the literature, the methodological process of identifying a sample size could be based on data saturation, and therefore, the sample size is justified by interviewing respondents till data saturation can be achieved.

Furthermore, researchers can also enhance the reliability and validity of their qualitative findings by employing rigorous data collection and analysis techniques (Miles, 2014). In that case, researched tried to carefully selecting participants who can provide rich, relevant information that can improve the transferability of qualitative findings. Actually, the interviewees were selected from the construction professionals of the UK construction sector, focusing on taking interviews with senior team members such as the head of the engineering team, senior design managers, Project managers, directors, etc. The respondents' experience ranged from 3 to 20 years.

Also, researcher attempted to clearly document the research process, including the rationale for decisions made, to enhance transparency. Overall, while qualitative research methods have their limitations, they can be effectively overcome by incorporating complementary approaches, ensuring appropriate sample sizes, and employing rigorous data collection and analysis techniques (Miles, 2014; Creswell, 2018; Merriam, 2016).

3.4.2 Quantitative research methods

Quantitative study uses and develops hypothesis, theories, and mathematical models to understand and describe relevant natural phenomena. This study's primary goal is to examine a theory composed of variables, identify discrepancies, analyse statistical procedures, and make connections due to determine whether predictive generalisations of the theory hold true (Goddard, 2004; Guba and Lincoln, 2005).

Unlike qualitative research, Naoum (2013) argued that quantitative study was predominantly used in social research, collects and analyses numerical data rather than words and meanings. Quantitative research method is commonly connected with case studies, archival research, survey, research strategies, and experiments. According to Saunders et al, (2012), survey and experimental approaches are the two main approaches that is adopted within quantitative research employs standardised measurements for gathering different viewpoints from respondents who will fit into a certain number of established response categories.

Experimental research can be identified as a group of research practices and designs that use carefully controlled experiments to consider processes in the natural sciences. Naoum (2013) claimed that experimental strategy uses predictive hypotheses to understand the nature of the research question as the vast majority of management research inquiries could have been designed to examine connections between variables rather than a relationship that was predicted. The major strengths and characteristics of the quantitative research method are including (Goddard, 2004; Guba and Lincoln, 2005; Naoum, 2013):

- The research issue can be identified in detailed and specific terms.
- Specifying dependent and independent variables can be clearly and precisely.

- Minimise or eliminate subjectivity of judgment to test and analyses the theories and get the ideal results.
- Ability to allow researchers to access highly reliable data that could possibly be used to monitor and control observations, lab tests, or other types of research experiments.
- Enable the researcher to obtain long-term evaluations of the study subjects' performance.

The main characteristics and weaknesses of the quantitative research approach are including (Goddard, 2004; Guba and Lincoln, 2005; Naoum, 2013):

- lack of providing the researcher with details on the specific conditions in which the phenomena under study happens;
- being unable to control and manage the environment in which survey respondents answer to questions;
- Due to the closed-ended nature of the questions and the structured framework, results were restricted to just those included in the original study's proposal;
- Not encouraging the evolving and continuous investigation of a research phenomenon.

3.4.3 Mixed-methods technique

Regarding the benefits and drawbacks of both qualitative and quantitative research methods technique, there is a widely accepted view that combining these two methodologies can reduce or neutralise the bias of research methodology. So, in comparison to mono methods, mixed methods described as the utilisation of many data collection methods in support of a variety of research strategies so that they can be applied to various ontological hypotheses to address the subject matter of the research (Newman, 1998).

Bryman, (2008) argued that inductive or deductive approach or a combination of the two can be used in designing mixed methods research to test a theoretical proposition and to develop a richer theoretical perspective. Also, he claimed that quantitative and qualitative research methodologies are not divergent or antithetic, further exploration of the study's conception and execution, the underlying consistency could become apparent. The mixed method researchis usually adopted within management and business research as it will offer more potential of data collection, interpretation and analysis (Bryman, 2008).

The three principal decisions that a researcher must make to design a mixed-method research are including (Beiske, 2007):

- Considering adopting equal priority of both qualitative and quantitative research method.
- Conducting concurrently or sequentially stages of the qualitative and quantitative research method.
- Where combining of the quantitative and qualitative research methods can occur.

Following conducting sequentially or concurrently through the mixed methods research, Creswell et al. (2009) asserts that there are several phases of analysis and data collection in a sequential research approach, and the results of one method are informed by the knowledge and data from the earlier approach. Whereas, in comparison to the sequential mixed methods, the mixed method research approach conducts a single phase of qualitative and quantitative analysis and data collection. Also, mixed methods research will be designed equally or unequally through the research project that involves primary (core) method or either more supplementary components of research methods such as qualitative or quantitative which provides insight into the research project's core component. In addition, the participants of thecore and primary may not be the same but must be selected from the same population (Creswell et al, 2009).

According to Bryman (2008), the significant strengths of mixed methods research are including:

- Allow the researcher to adopt pictures and words that will be conducted to add meaning to the numbers.
- Enable the researcher to provide qualitative and quantitative research method strengths and weaknesses that combining quantitative and qualitative research methods can provide more comprehensive information that is required for informing practice and theory.
- Allow the researcher to test and generate grounded theory.

- Researcher by conducting single method or multi method approach will be answered a complete research question.
- Provide researchers an opportunity to utilise the advantages of a different research approach to overcome the research method's shortcomings.
- Through corroboration and convergence of data, this research strategy enables the researcher to establish a conclusion with greater evidence and documentation.
- It will be utilized to increase the generalisability of the outcomes of the research.

According to Bryman (2008), the significant weaknesses of mixed methods research areincluding:

- If two or more research technique approaches are planned to be executed concurrently, it will be challenging for a researcher to organise and carry out both quantitative and qualitative research.
- Multiple research methods and approaches must be learnt by the researcher.
- The cost of the research will be increased by adding and adopting the other research methods, so it will be more expensive.
- By adding and adopting the other research methods than single research method, the researcher will spend more time to understand how to mix the research methods appropriately.
- How to interpret conflicting results, how to qualitatively analyse quantitative data, and problems of mixing paradigm are the other significant disadvantages of using mixed method research.

3.4.4 Methodological Choice adopted by this research

Methods that are expected to be used shall rely on the types of data collected, whether it is numerical or based on personal options or both. There are three main methods that are identified in this layer. They are known as follows: Quantitative, Qualitative, and Mix Methods. Bryman (2008) claimed that mixed method has been seen as an emerging area of researchstudy, which has a several benefits especially within the built environment area.

By considering the Industry 4.0 technologies and rapid technological changes in the construction processes, qualitative research method is adopted to address the different layer ofthe research study to explore and address the research questions to meet the aim and objectives of the research.

This research will start with an extensive investigation of the literature available on digital transformation, the role of Industry 4.0 technologies such as IoT application in the UK construction sector to identify and recognize any gaps in knowledge and evaluate available literature on the research study.

A qualitative research approach is adopted to understand the impact of conducting IoT application on the performance, productivity, profitability and delivery of the project. The qualitative data is collected through interviews with participants from construction organisations that are involved in the digital transforming the UK construction projects. Therefore, qualitative research approach is employed in this study to achieve differentobjectives respectively.

3.5 Research strategy

According to the layers of the research methodology, the next layer of the onion will be the research strategy. This layer enables the researcher to use one or more strategies within their research design to understand how to answer questions properly. Saunders et al. (2012) argued that the main research strategies are including case study, grounded theory, ethnography, survey, archival research, action research, and experiment.

Also, in some cases the boundaries between research strategies are often permeable and researchers are not limited to associate particular research strategies with particular research philosophies, for instance, ethnography is associated with both interpretivism and realism. In addition, the survey research strategies and the experiment are commonly associated with pragmatist, realist, and positivism. Case study as one of the researchstrategies is often associated with interpretivism and positivistic research (Saunders et al, 2012)

3.5.1 Experiment

An experiment is usually identified as one of the most demanding strategy to reduce different explanations of results. Actually, an artificial environment within elements and events that controlled separately will create the well-designed experimental research. This will be achieved by casually assigning the particular treatment to control a group. The experimental research strategy is usually employed in a positivist research context that relevant with the quantitative research. Creswell et al (2009) stated that the experimental research strategy by contributing in large measure enable researchers to analyse and understand their relations of cause and effect more clearly and rapidly.

The significant disadvantages of experimental study are including personal biases, results can only be applied to one situation, artificial results, unreliable samples, and results may be hard to replicate. Moreover, the outcomes may not be generalised to real life conditions. In addition,this strategy will be expensive, time consuming, and sometimes experiments may not be conducted to the practical and ethical considerations (Creswell et al, 2009). This strategy is not considered to its underlying and testing the application of this study, so, the researcher in this study does not seek to empirically test a new thing in a new setting that considered to develop a framework for implementation of the Internet of Things (IoT) application that will useful for stakeholders to understand and impact of IoT adoption in the UK Construction sector.

3.5.2 Survey

A survey is a research strategy and can be described as a non-experimental inquiry that employs in natural systems to generalise data resulting from sampling populations. In a survey research strategy, questionnaire or a structured interview are the two main tools that the researchers can utilise to collect the data and explore the patterns of connections between variables in the research study. Survey research relies commonly on quantitative and quantitative research methods to explore patterns that will be generalised to the overall relevant community. So, this strategy can suitable for adopting in a positivist philosophy (Creswell et al, 2009).

According to Bryman, (2008), the significant advantages of adopting survey research strategy are including as little or no observer subjectivity, precise outcomes, convenient data gathering, low costs, good statistical significance, and high representativeness. Conversely, the significant disadvantages of adopting survey research strategy are including as possible inappropriateness of questions, inflexible design, and not ideal for controversial issue (Bryman, 2008). Thus, by considering the characteristics and nature of the survey research strategy, this strategy was not selected in this study.

3.5.3 Action Research

The term of action research is considered as another research strategy that associated with the practitioners and researchers working in a partnership to recognise and address complex real issues. This research strategy came to prevalence in the late 19^{th} that conducted by individuals who require to increase their discovering and understanding of practice within an organization. This type of research strategy allow the research to participate in the change process and get practitioner feedback to improve and develop the research findings. The action research strategy is aimed to improve dealings with others in a social context that normally used in the business management area. Also, it involves people within the organisation to identify problems and provide suitable solutions. In addition, this type of research strategy can be associated and adopted with the positivist, an interpretivist, or a critical study stance (Creswell et al, 2009). Goddard (2004) claimed that the significant disadvantages of adopting action research strategy are including as lack of repeatability and rigour if there is a require to produce immediate research findings, difficulties in distinguishing between action and research, and time consuming and possibility of delays in the completion of study as care requires to be taken to maintain transparency of purpose. In order to adopting this strategy, the researcher should be able to establish a distinction clearly between action research and consulting and, since the former involves both action and research that goes beyond consultation, while the latter's important activities are restricted to action alone. This research method was not considered applicable for this study due to the nature of the problem, which seeks to identify and highlightvarious possibilities for research area associated with industry 4.0 in the UK Construction sector.

3.5.4 Grounded theory

Grounded theory is a systematic methodology in social science research that involves the construction of theories through methodical gathering and analysis of data (Baskerville, 1999).

Unlike other research methods that test existing hypotheses, grounded theory is inductive, meaning it generates hypotheses and theories from the data itself. This approach was developed by sociologists Barney Glaser and Anselm Strauss in the 1960s and has since become a prominent method for qualitative research (Pace, 2004).

The Grounded Theory Process

The primary goal of grounded theory is to develop a theory that is grounded in, or emerges from, the data. This process involves several key steps:

1. Data Collection: Data can be collected through various qualitative methods such as interviews, observations, and document analysis. Unlike traditional methods that require a pre-determined hypothesis, grounded theory starts with a broad area of interest (PriesHeje, 1992).

2. Open Coding: This initial phase involves breaking down the data into discrete parts, closely examining, and comparing these parts for similarities and differences. Codes are assigned to chunks of data that appear significant (Smit, 1999).

3. Axial Coding: Here, the researcher identifies relationships among the open codes. Axial coding involves reassembling data in new ways after open coding, to explore how codes relate to each other (Pace, 2004).

4. Selective Coding: In this stage, the researcher integrates and refines the theory. Selective coding involves identifying a core category and systematically relating it to other categories, validating those relationships, and filling in categories that need further refinement (Galal, 1997).

5. Theoretical Sampling: Throughout the process, researchers may return to collect more data to fill gaps, refine categories, and deepen the emerging theory. This is known as theoretical sampling, where the aim is to gather data that enhances the developing theory (Smit, 1999; Pace, 2004).

6. Constant Comparison: A crucial aspect of grounded theory is the constant comparison method, where data is continuously compared with emerging categories and concepts, ensuring that the theory remains grounded in the data (Smit, 1999).

7. Memo Writing: Researchers write memos throughout the process to capture their thoughts,

insights, and theoretical ideas. Memos help in developing and refining categories and theories (Smit, 1999).

Benefits of Grounded Theory

1. Theory Generation: Grounded theory is particularly useful for generating new theories where little is known or existing theories seem inadequate. It allows for the discovery of patterns and relationships that are truly grounded in empirical data (Pace, 2004).

2. Flexibility: The method's inductive nature allows researchers to adapt and change directions based on what the data reveals. This flexibility can lead to richer and more nuanced understandings of the research topic (Smit, 1999).

3. Contextual Richness: Grounded theory provides a deep understanding of the context and processes involved in the phenomenon being studied. It captures the complexity and subtleties of human behavior and social interactions (PriesHeje, 1992).

4. Participant Perspective: By focusing on the data and the participants' perspectives, grounded theory ensures that the resulting theories are closely aligned with the lived experiences of those being studied (PriesHeje, 1992).

Disadvantages of Grounded Theory

1. Time-Consuming: The iterative process of data collection, coding, and analysis can be very time-consuming. Researchers must be prepared for an extensive commitment to the project (Galal, 1997).

2. Complexity and Skill Requirement: Grounded theory requires a high level of analytical skill and reflexivity. Researchers must be adept at managing large volumes of data and at identifying and developing theoretical insights (PriesHeje, 1992).

3. Subjectivity: While grounded theory aims to be systematic, the process can be subjective. Researchers' biases and perspectives can influence how data is interpreted and how theories are developed (Smit, 1999).

4. Generalizability: Because grounded theory focuses on depth rather than breadth, the findings may not be easily generalizable to larger populations. The theories developed are context-specific and may not apply broadly (PriesHeje, 1992).

5. Difficulty in Ensuring Rigorousness: Ensuring the rigor and credibility of grounded theory research can be challenging. Researchers must carefully document their processes and justify their methodological choices to demonstrate the validity of their findings (Galal, 1997).

Grounded theory is a powerful methodology for qualitative research, particularly suited for exploring complex phenomena where existing theories are insufficient. Its inductive nature allows for the development of theories that are deeply rooted in empirical data and reflective of participants' lived experiences.

However, the method's advantages come with challenges, including its time-intensive nature, the need for high levels of skill, and potential issues with subjectivity and generalizability. Despite these challenges, when executed rigorously, grounded theory can provide profound insights and contribute significantly to the understanding of social phenomena (Galal, 1997; PriesHeje, 1992; Smit, 1999).

So, following selecting the research methodology, a grounded theory is adopted for this research that enable the researcher to obtain the objectives of this study to assess the role of the internet of things (IoT) in enhancing the performance of UK construction industry.

3.5.5 Ethnographic Research

Ethnographic research as one of the significant research strategies can be aimed to interpret and describe shared patterns of language and behaviour of participants. This strategy is qualitative in nature that enable the researcher to involve in the social life of participants for the period of time due to make conclusions from the approach of participants who has being examined.

These approaches will be conducted in different ways including informal correspondence such as e-mail, informal interviews, and observation (Guba and Lincoln, 2005).

However, as this strategy is associated with the context of what people understand and believe, some of the researcher claimed that the term of ethnography can be used as a data collection technique rather than a research strategy design. So, the researcher for adopting this research strategy should be focus upon interpreting and describing the social group of the research study. Also, the researcher must be ensured the balance between the perspectives of inside and outside of the social group to remain open minded. This research strategy is usually implemented in the field of information management research (Goddard, 2004). Following the nature of the problem and philosophy of this research study, the researcher does not tend to study physiologies or behavioural patterns of participants that is not appropriate for this study.

3.5.6 Archival Research

The term archival research is indicated that the researcher can employ the information and data from existing archival records. So, the researcher does not tend to take part in gathering data. So, the researcher is not personally involved in observing the events and collecting the data. The census as a government collected information data is one of the examples of archival research that researcher can use without involved personally. So, archival research will be useful for the type of theories and hypotheses where it is impossible to ethically assign participants to social groups. One of the significant disadvantage of adopting this research strategy is that the researcher has no control over how the data was collected (Goddard, 2004).As a result, the archival research was not considered to the nature of problem in this study, which seeks to identify and highlight potential research areas related to industry 4.0 for the UK construction sector.

3.5.7 Case study

According to Bryman (2008), a case study is an empirical investigation that explores a modern phenomenon in its actual context, particularly when the boundaries between the two significant factors of investigation such as context and related phenomenon are not certainly evident. This strategy will be a group, organization, or single person to examine a phenomenon in a usual situation (Bryman, 2008).

The case study aimed to gain a comprehensive knowledge of research investigation to provide a rich mix of data that can be associated with quantitative and qualitative data. This methodology approached with the investigation of a single or multiple cases that will be categorized as descriptive, exploratory, or explanatory in real life context. An explanatory case study is normally utilized to develop a hypothesis and phenomenon in a large research project, whereasa descriptive case study is often employed to refer to process. An exploratory is another case study strategies that normally utilised to test the phenomenon to gain the logical conclusions. Also, Creswell et al (2009) claimed that the research questions such as why and how are commonly used in explanatory research case studies.

Bryman (2008) states that the case study as a significant research strategy can be useful in different ways that are including; the investigation of issue, concern, program, and inquiry to decide on suitable research questions to encourage future study; also, it can be useful to the clarification of linkages between causes and effects; allow the researcher to investigate the description of a real-life context and intervention to test the phenomenon and hypothesis.

There are several benefits that can be obtained by adopting this research strategy than the other methodologies.

According to Bryman (2008), one such benefit is that this research strategy can be useful as a primary source of valuable information to researchers. A further benefit of implementing a case study research approach is that the in depth analysis of data and information delivered more concrete and contextual (Bryman, 2008).

3.5.8 Research Strategies adopted by the research

In this research study, the adoption of grounded theory could appear to be a reasonable approach, especially in combination with a pragmatic research philosophy and a qualitative methodology. Sociologists Barnay G. Gleser and Ansalm L. Stress' research resulted in the development of grounded theory in the early 1960s. They presented their methodology in the article "The discovery of grounded theory," in which they claimed that methodological qualitative analysis could produce logical theory (Beiske, 2007).

Investigation identifies grounded theory's key components such as follows:

Collaborating on data collection and analysis simultaneously.

- Analytic categories are derived from data, not considered preconceived hypotheses.
- The constant comparative approach compares stages of analysis.
- Enhancing theory development through data collection and analysis.
- Memo-writing helps define categories, and properties, defining gaps and relationships.

Following the above definitions, the grounded theory could be identified as a dynamic methodology requiring constant comparison, aiming to create theories for qualitative data.

Grounded theory, established by Glaser (1978) and Strauss (1987), allows researchers to employ flexibly in their research strategies. Researchers like Charmaz (2014) defined grounded theory methods as a group of practices that could be implemented based on the investigation. The study uses research methods like semi-structured interviews to collect the data, and content analysis to analyse the data, which will be used for the development of the framework.For this purpose, deep investigation is needed to answer the research questions, such as:

- In terms of digital transformation, how Industry 4.0 technologies, particularly Internet of Things (IoT) applications could impact on the UK construction sector?
- What significant factors could prevent stakeholders from embracing digital tools and techniques such as the Internet of Things (IoT) through smart construction systems?
- What are the considerable factors that could influence stakeholders to adopt the industry 4.0 technologies such as Internet of Things (IoT) applications in the UK construction sector.

All of these questions will be answered with grounded theory strategy by collecting and analysing the data from semi- structured interviews through the research.

3.6 Data Collection Research Techniques

Creswell et al. (2009) claimed that the data collection and then analysis them could be the pivotal part of any research. The literature review and semi structured interviews are the two techniques that the researcher is adopted for this study and in the following sections each techniques are further discussed and explained in the context of the research study.

3.6.1 The literature review

The literature review, in accordance with Saunders et al. (2012), is essential to comprehend and determine the gaps in the current state of knowledge in the field of study. Also, Bryman (2012) argued that the literature review is a fundamental and basic technique that ensure that the researcher to know and understand what has gone before and illustrates why the research is significant.

Following adopting the literature review, this study implemented two stages of the literature review are including as; In order to fully understand and explore the research challenges and gaps that will help define the research's goals and objectives, the first stage commences by identifying the present challenges facing the UK construction idustry.

After recognising and identifying aim and objectives, a more detailed literature review was implemented form knowledge regarding to identify and illustrate potential research areas connected with the industry 4.0 into the UK construction sector that will be concentrating on the fundamental and theoretical concepts. Moreover, the second stage of the literature review presented to justify, explain, and validate the research findings.

3.6.2 Interviews

The interview as one of the well-established techniques in qualitative research will be fulfil several research aims and objectives. Also, it could be employed in the same study at any stage when it may be combined with other tools and approaches for data collecting. In addition, Creswell (2009) stated that the interview will be described as the professional and purposeful conversation between the interviewer and the interviewee through the research interaction to capture the data and information.

According to Kvale (2007), one of the benefits of using this technique is that the researcher will be able to analyse of the interview during the interview process due to clarifies the understanding of meaning with the interviewee. Moreover, the interview will be recognised as an open process that the researcher captures information and data from a source or person. By considering face to face, internet, or telephone connection in interview process, the interview has a particular strength that it will yield data and information rapidly and in a great quantity (Beiske, 2007).

Although, it has weaknesses and limitations. For instance, Yin (2009) claimed that for implementing interview technique, capturing comprehensive data has a direct link with the valuable level of the researcher that some of the documents such as personal records will can be confidential. So, the opportunity to access these evidences may be outside the control of the researcher. Also, interviewees may be uncomfortable in sharing data and information on the subjects that the interviewer aims to explore and investigate.

Furthermore, the interviews by offering an opportunity for the researcher to reveal new

extents of a problem attempts to gather data regarding interviewee's opinions, impressions, knowledge, and experiences through the research. The semi-structured interviews as the most common type of interview are necessary for qualitative research methods. Interviews are regarded as one of the most effective methods for understanding individuals, according to a variety of authors. Therefore, for the purposes of this study, interviews are one of the methods most frequently used to gather information on the built environment (Beiske, 2007).
Fellows and Liu (2008) argued that Interviews can be divided into three categories namely as structured, semi-structured and unstructured interviews. According to Beiske (2007), semi-structured interviews is identified as the interviews that the programmed questions will be changed depending on the interviewer's opinions. However, Bogdan and Biklen (1992) stated that the participants being directed by the questions of semi structured interviews have been offered little room for variation in response to the interviewer questions except where an infrequent open-ended questions may be utilized.

According to Heaton (2004), Interviews will be exploratory or in depth that the exploratory interviews will offer new ideas, dimensions and provide greater depth to the original research question to develop the theories and hypothesis. Oppenheim (2000) stated that adopting of the exploratory interview in the research study is not only used to gather facts and statistics, but also to develop hypotheses and ideas in the practical and experimental nature.
Despite the introduction of computer communication such as chat forums and using social media websites to interview with participants, it is normal that for adopting qualitative research, researcher tend to implement the face to face interview than other alternatives forms. Also, researchers are usually hesitant in using the telephone as an interview tool with the participants. However, some authors believed that the telephone interview has many benefits over the face to face interview. Creswell et al (2009) stated that the telephone has many advantages associated with lower cost, speed, and easy access, when implementing interviews.On the other hand, some authors have not supported the suitability of the telephone for adopting in-depth interviews. They claimed that utilizing the telephone may lead to discourage participants to engage in an exploratory discussion due to reduce reliability and quality of interview (Creswell et al, 2009).

Therefore, the semi structured interviews by increasing the breadth and depth of the information and knowledge about the research questions is frequently utilised in the research field of the Built environment particularly in the construction industry. In effect, this study can probe specific themes related to the role of the internet of things (IoT) in enhancing the performance of UK construction industry, thus making semi-structured interviews an appropriate tool and technique to collect and gather data. Actually, in the situations when a researcher is familiar with the notion being researched, semi-structured interview is a recommended data collection technique.

Creswell et al (2009) recommended that the appropriate duration of a telephone interview could be between 15 and 20 minutes. However, participants are usually willing to engage longer in telephone interviews if participants are adequately motivated. The quality of the interview is often considered by several authors ass one of the significant factors to the achievement of the aims and objectives of the research study.

Actually, interaction between the researcher and the participant can identify the quality of the interview in any research. Recording the interview is one of the methods that can increase the quality of the interview. Saunders et al (2012) argued that audio recording will be useful through the various interview forms particularly in telephone interview as taking notes can prove difficult with this medium. Also, he suggested that these audio recordings require to be transcribed and then translated into the written words.

3.6.3 The interview strategy adopted by this research

The research involves collecting data from participants through semi-structured interviews to achieve the research aims and objectives in which that will be selected upon will rely on: 1) Level of experiences on using digital tools in construction, 2) knowledge of Internet of Things (IoT) and Industry 4.0, and 3) Number of construction projects using Internet of Things (IoT) tools. The selection of organization and practices will be based on multi-level experiences to support their transformation from traditional methods toward digital construction techniques. The criteria that organization will be selected on will rely on the following outcomes: 1) Industry tools being operated, 2) amounts of construction projects that Internet of Things (IoT) being used in, 3) level of experiences on the implementation of IoT in construction projects. Aselection of some disciplines could include the following: Senior managers, project managers,and operational managers.

The researcher will not use any personal details of the participants and will maintain anonymitywith them, where all of the participants will have the right to enquire about their involvement within the particular research from the researcher. Therefore, all information will be collecting during the Ph.D. study and in order to ensure anonymity when analysing and assessing the data, it will be kept in absolute confidence. Additionally, all data will be coded, saved electronically on a password-protected computer with only the researcher having access to it, and deleted once it is no longer useful for the research.

After selecting the senior professionals participants from various UK construction companies, an invitation letter along with the participant information sheet shall be emailed to them to invite them to participate and deliver an overview of the research and their involvement roles. Further to this email and avoiding to have a face to face interview in some cases, the researcherwill ask them to have a E-meeting such as Zoom meeting or Skype interview that will be more convenient for both interviewer and interviewee instead of the face to face interview. A reply to the emails with approval and signing a consent form will ensure that informed consent (which clearly showing that personal details will be kept confidential throughout the research) has been obtained and the participant is willing to participate in the interview process of the research.

The selected participants will be done through a non-probability sampling technique of 5-45, since it will be required to consider the region of the suggested numbers towards achieving the required upper limits and not less than the lower limits (Saunders et al., 2012). The participants were contacted through personal contacts, networks, conferences, in which the interviewers may recommend and suggest other users to interview through the digital construction forums. In order to collect the appropriate achievable information that will allow analysis and assist in the proper formation of questionnaires, associated with 15to 45 interviews (based on comparable previous studies) will contribute to this research. A comprehensive format of open-ended questions was used in each interview, which lasted approximately one hour to complete. The construction professionals were selected with the professions as follows: Senior managers, Operational managers, BIM coordinators, Project managers, etc.

The interview questions were divided into main three sections that are follows as:

- Background Information on digital transformation, industry 4.0, and Internet of Things (IoT).
- Understanding the organisational and project requirements of using IoT
- Develop the framework for implementing the Internet of Things (IoT) in the UK construction sector.

The first section was focused on obtaining background information of the participants relevant to their organization, experiences, and particular digital tools and services in adopting the industry 4.0 technologies particularly IoT in the UK construction sector. Some of the significant questions of this section were as follows:

- Following digital transformation concepts, where do digital technologies stand in your organisation in terms of its adoption?
- What are the main areas of the Internet of Things (IoT) application in your company?
- In terms of adopting the Internet of Things (IoT), what are the current tools being used in your construction company? Why?

The second section was provided to understanding the organisational and project requirements for implementing the Internet of Things (IoT) in the UK construction sector. The benefits and challenges of implementing the Internet of Things (IoT) were utilized to recognize the key influencing factors of adopting this technology that the stakeholders can consider achieving the better project performance and faster delivery of the project. In addition, it gathers the perceptions of the respondents in relation to adopting the various IoT tools in different stages of the construction site. Some of the important questions of this section were follows as:

- What are the main drivers and challenges in the process of increasing digitalisation with the concept of Industry 4.0 in the UK construction sector?
- What are the significant benefits and challenges of implementing the Internet of Things (IoT) in your company? Why?
- Which benefits are expected to emerge for your company from the usage of the Internet of Things (IoT) and BIM both operate together? Why?

Finally, the last section was focused on gaining information from the respondents to develop the framework for the Implementation of the Internet of Things (IoT) in the UK construction sector. It also considered the several factors that influence stakeholders to accept or prevent embracing smart construction tools such as the Internet of Things (IoT) in the UK construction sector. Some of the important questions of the last section were follows as:

- What are the possible relationships among Machinery, People, and Internet of Things (IoT) connectivity due to improving productivity in the construction Industry?
- Which factors impact on the Construction Industry to be the least digitized sector and reluctant to innovate than the other sectors?
- To what extent can Industry 4.0 technologies such as the Internet of Things (IoT), Big data, Cloud Computing, Virtual Reality, and so on impact on the UK construction sector?
- What are the key influencing factors for implementing the Internet of Things (IoT) application in the UK construction sector?
- What elements prevent stakeholders from embracing smart construction tools and techniques?
- What are the factors that influence stakeholders' acceptance of industry 4.0 technologies such as the Internet of Things (IoT) in the UK construction sector?
- What are the potential drawbacks for SMEs that are not reluctant to invest in adopting digital technologies in the construction Industry?

Therefore, in order to acquire deep and rich quality information, have better control over the interview process, and avoid obstacles connected to the privacy of shared information, semi-structured interviews from the various UK construction project managers were taken in this study. So, interviews through the UK construction project managers were used as the supporter source of evidence to cover the requirements for study validity and reliability. Recording techniques were adopted within the interviews, and note-taking techniques were employed to avoid detailed transcribing that may consume additional time. After collecting the data fromthe respondents, thematic analysis, an appropriate tool for data analysis and reporting, was used.

3.6.4 The questionnaire survey

Researchers in the field of built environment often investigating questions by implementing surveys either by questionnaires or interviews. Questionnaires as one of the survey techniques allow the researcher to collect data, often numerical, from a large population in an economical and efficient way to compare their perspectives (Creswell et al, 2009).

Oppenheim (1992) argued that this technique by gathering data and information about the behaviour, attitudes, and knowledge from a large population of the people can ensure the researcher to analyse the data in a static approach. According to Oppenheim (1992), some of the main advantages of adopting questionnaires in research project are including such as feedback will be offered to participants, questionnaires can be less intrusive for respondents, the speedy collection of data, and participant's responses are often anonymous.

However, Creswell et al (2009) claimed that the questionnaires by collecting quantitative data may be failed to explore explanations and meaning of the research objectives deeply as particularly in the built environment area. In fact, it can give an overview of how measuring the variables can be impacted by temporal changes that they would not be able to identify in just a single survey (Creswell et al, 2009).

Also, Goddard (2004) claimed that other disadvantages of using questionnaires in a research are including such as lack of the confidence to respond it properly and the lack of direct interactions may end up resulting in quality responses, which might be avoided by improving the Structure, design, and wording. Furthermore, Beiske (2007) contends that a good questionnaire is the one that can provide answers to the all question. Also, the questions by considering knowledge, opinion, and facts should be unambiguous, unbiased, and intelligible. Also, it is crucial to carefully assess the questionnaire's design, subject, sample, and duration (Beiske, 2007).

Following the size of the sample in questionnaires, the researcher is needed to set up and consider the accurate and acceptable lists of the respondents. So, Guba and Lincoln (2005) claimed that a questionnaire will be classified to three different types that are including Structured, Semi-structured, and Unstructured. Structured questionnaire is considered closed questions that will support the analysis via statistical data. Also, semi-structured questionnaire included the open-ended questions that allows respondents to focus on their answers in specific required ways. The unstructured questionnaire, as another classified questionnaires, involves open-ended questions that let the respondents to write their opinion about the question with minimal structuring (Guba and Lincoln, 2005).

Bias is identified as one of the significant issues in designing a questionnaire. So, the researchers should able to prevent making bias in designing of their questionnaires to get the reliable survey. According to (Choi and Pak, 2005), the three main types of bias in designing a questionnaire are including: issues and problems with the wording such as the question could be complex, too short, ambiguous, and double barreled; or inadequate and missing data such as faulty scale and format, overlapping interval, and insensitive measurement; or leading questions such as inconsistency, framing, and sensitive question.

Saunders et al, (2012) stated that there are several ways that the researcher will measure the questionnaire including, rating, ranking, and listing. In this research, the participant's level of agreement with each of the statements is measured using a Likert scale, which is additionally employed to rate the questions.

The Likert scale enables participants to assess statements in a set of questions to determine agreement or disagreement. Also, in order to remove the research's bias, there is a neutral option available for those particular individuals who did not respond to the study. So, if a scoreis required for a number of variables in this research, each variable will be analysed individuallyor as a group. However, for the researcher who wants to adopt the Likert scale in their research, there is much debate in research market to the selection of the appropriate number of scale points to specify their level for each statement. By adopting Likert scale in this research, the researcher allocated the Likert scale of one to five that involves a neutral option as a third option to reduce the likelihood of bias.

However, it has been determined that the neutral response can be the key source of disagreement. Therefore, the researcher attempts to motivate respondents to answer each question thoughtfully and choose the best acceptable response by including positive as well as negative statements in the questions. Also, the questionnaire should be piloted and be clear wording free from jargon. Furthermore, the length of the questions should be sufficient for the respondent to fully understand and respond in line with the purpose of the question being asked. The piloting can be tested whether the questions of the questionnaires are unambiguous, easy to interpret, and intelligible. In addition, feedback of the participants can provide the opportunity for the researchers to improve and determine of the time required for completion of the questionnaire.

In some cases, questionnaire surveys could be designed to add the data to the interviews. So, the questionnaire survey can provide the opportunity for researchers to gain more particular data and information from a larger number of respondents than interviews survey. For designing the questionnaire, the questions should be structured to produce the nominal ordinallevels of measurement. It is significant that the choice and level of the measurement can affect the type of data analysis which is implemented. In this kind of questionnaire, bar charts, frequency distribution, and cross tabulation should be utilized to present the survey outcomes (Creswell et al, 2009).

3.6.5 Data collection techniques adopted in this study

In order to answer the research questions, this study aims to gather information on the impacts of implementing Internet of Things (IoT) applications in the Uk Construction sector, identify drivers, challenges, and finally refine data collection techniques.

The study involved semi-structured interviews with 38 construction professionals in the UK Construction sector. Snowball sampling was employed in order to access new participants through the contact information, which was provided by other participants, a widely used method in qualitative research study across social sciences.

In this research, the selection of a sample size for qualitative research is influenced by previous experiences. Mason (2010) by analysing qualitative PhD studies suggested that researchers could be required to apply for 5 to 80 interviews, mean value of 25. Furthermore, Creswell and Poth (2017) recommend 20 to 60 interviews could be suitable in this regard. In addition, according to the literature, the methodological process of identifying a sample size could be based on data saturation, and therefore, the sample size is justified by interviewing respondents till data saturation can be achieved.

Research involving human participation needs institutional ethical approval. The lead researcher filled out the form, which was then submitted to the University of Salford ethics committee. Interviews were recorded and transcribed, producing a verbatim transcript without consideringnuanced factors like voice inflection or laughter. Interviews were conducted from January 2022 to September 2022 through the constructionprofessionals of the UK construction sector, lasting 30 to 45 minutes. The research study employed the following code: It started with UK – INF as representative of the construction sector in the UK, followed be respondents' numbers. For example, UK – INF – 001.

3.7 Time Horizon

The time horizon as one of the research onion layers is focuses on completion of the research study within any time limits. Time horizon can be divided in two different categories including Cross-sectional and Longitudinal studies. As a PhD student with limited time period to complete the study, all stages and activities of the research such as designing the research aim and objectives, collecting data, and analyzing the data to get the results have to end within this period time of study.

Cross-sectional studies are reoffered to as resolving problems of research and conducting in a controlled amount of time. So, in cross-sectional studies a researcher will resort to working on different stages of the study at one time. However, longitudinal studies can be identifies as resolving the problems of research and conducting in an open time frame. So, f a researcher is only allowed to work on a particular phase of the research at a time and each phase depends on the outcomes of the previous phase, the findings will be released at various study times without deadlines. Bell (2014) argued that the deadlines of the research activity must be stated clearly at the outset of the study to get the comprehensive results with the limited time.

Moreover, Bell (2014) believes that the time pressure can lead to get the quick answers from the researchers. In other word, if the researchers are aware of the limited time period at their study, this will become an overriding factor when they schedule to the design a research.

According to Bryman (2012), the cross sectional research approach is normally used in both quantitative and qualitative research to adopt interviews and questionnaire survey to collect the data in studies. This study is conducted as a PhD research thesis that must meet the university procedures and rules for collecting the data and presentation of findings in time. Therefore, this research is adopted Cross-sectional time horizon due to time constraints set for this research; in regards to deadline set for delivery in a controlled timeframe, and nature of the research that restricts an open timeframe.

3.8 Data analysis

Creswell et al. (2009) argued that one of the most important aspects of any research that enables researchers to review and investigate the information in order to generate conclusions is analysing the data and information gathered to gain the study's outcomes. According to Goddard (2004), analyzing data will be started with the disassembling and breaking up of the research materials into elements, pieces, units, or parts.

So, the researcher by reconstructing or assembling the data in a meaningful way seeks to get the patterns, sequences, types of the qualitative or quantitative data to address and solve the initial propositions of the research. In addition, the researcher could generate theories and ideas that are validated by facts by using the technique of data analysis. In the following section, the researcher will describe the qualitative data analysis techniques that was adopted in the research study.

3.8.1 Sample size

As states by Saunders et al (2012), the term "sampling" refers to a technique where units from a group of individuals are chosen to participate in the data gathering of the research. The sufficient size of a sample has a direct link to satisfy the requirements of the statistical data analysis. If the researcher conducted the larger sample size, it can lead to get the closer distribution and more robust findings. Also, Bryman (2015) stated that there are no absolute thresholds can be considered as the minimum sample size of parameters including the loadings, number of variables per factor, and the level of commonalities.

According to Saunders et al. (2012), two types of the sampling techniques in conducting research study are including Probability sampling and Non-probability sampling. The term probability or representative sampling refers to the units from the population that selected randomly. Goddard (2004) claimed that probability sampling techniques are usually conducted in survey studies when statistical implications are required to analyse data. As stated by Saunders et al. (2012), the process of the representative sampling will be categorised into four stages.

Firstly, utilise the study objectives and questions to determine an appropriate sample frame. Adopting an appropriate sample size will be the following step, followed by choosing an appropriate technique and the sample. Then, the sample's representation of the population should be verified in the end. So, adopting questionnaire technique can lead to employ probability sampling in this research. Also, Non-probability or judgmental sampling techniques are conducted through the research when the research objectives need another form of sample selection. According to Saunders et al. (2012), the four key methods of sample selections are including purposive sampling, convenience samples, snowball and self-selection sampling, and quota sample. When a sample is chosen with a specific objective, Purposive sampling could be utilised. Then, involves convenience samples where the sample is selected from elements of a population.

The next phase is volunteer to select from two classes that are self-selection or snowball sampling, and finally, quota sample that sample can be classified into groups based on certain elements. Also, this technique has been identified as the expert sampling or homogenous sampling when the purpose of the data collection is to establish an in-depth understanding of the issues. Following the sampling in this research study, 38 construction project managers from different types of construction sector were contacted to participate in the interviews.

3.8.2 Qualitative data analysis

As ‘text’ has a vital role in describing qualitative research approach. In analyzing qualitative data, the researcher can analyse the text that will come from notes of the participant observation or an interview transcription. According to Bryman (2015), there are different stages to analyse qualitative data. The initial stage is to document the data and the data-collecting process. The data will then be organised and connected into concepts as the following stage.

Next, the data are then confirmed by evaluating alternative explanations, searching for negative cases, and ultimately presenting the results (Bryman, 2015). Transcribing the interviews is one of the pivotal parts of the qualitative data analysis that allows the researcher to become familiar with the collected data before analysing data. These documents should be protected in a safe and secure file, accessed only by a researcher. The analysis of the interviewswas started with the intra-case analysis of each participants and the researcher utilised the qualitative data analysis such as thematic analysis for data coding and analysis.

The interviewees were selected from the construction professionals of the UK construction sector, focusing on taking interviews with senior team members such as the head of the engineering team, senior design managers, Project managers, directors, etc. The respondents' experience ranged from 3 to 20 years. Tables 1 displays their primary information regarding positions, the size of the company, the Professions, and years of experience. The reference code allocated to each participant is utilised in chapters four to ten to quote them, as shown in Table 1.

Table 1 Interviewee Information

Code	**Job Title**	**Size of company**	**Years of Experience**
UK-INF-001	Director	Large	>15
UK-INF-002	Director	Medium	>12
UK-INF-003	BIM Manager	Large	>5
UK-INF-004	BIM Manager	Medium	>7
UK-INF-005	Project supervisor	Medium	>4
UK-INF-006	Director	Large	>12
UK-INF-007	Senior Project Engineer	Large	>8
UK-INF-008	Contract Manager	Small	>7
UK-INF-009	Project supervisor	Small	>3
UK-INF-010	Operation Manager	Large	>14

Code	Job Title	Size of company	Years of Experience
UK-INF-011	Contract manager	Medium	>4
UK-INF-012	Senior Design Manager	Medium	>15
UK-INF-013	Project supervisor	Small	>3
UK-INF-014	BIM Manager	Large	>10
UK-INF-015	Project supervisor	Medium	>4
UK-INF-016	Operation Manager	Large	>8
UK-INF-017	Contract manager	Large	>7
UK-INF-018	Senior Project Engineer	Medium	>6
UK-INF-019	Project Manager	Large	>16
UK-INF-020	Consultant	Medium	>5
UK-INF-021	Project Manager	Medium	>11
UK-INF-022	Senior Design Manager	Small	>6
UK-INF-023	Consultant	Small	>5
UK-INF-024	Head of Engineering	Large	>11
UK-INF-025	BIM Manager	Large	>16
UK-INF-026	Technical Director	Small	>15
UK-INF-027	Project Manager	Medium	>7
UK-INF-028	Contract Manager	Medium	>10
UK-INF-029	Project Manager	Medium	>11
UK-INF-030	Technical Director	Small	>9
UK-INF-031	Head of Engineering	Small	>11
UK-INF-032	Project Manager	Medium	>18

UK-INF-033	Contract Manager	Medium	>14
UK-INF-034	Technical Director	Small	>12
UK-INF-035	Consultant	Small	>8
UK-INF-036	Project Manager	Medium	>11
UK-INF-037	Director	Small	>10
UK-INF-038	Technical Director	Small	>7

3.8.3 Content and thematic analysis

The thematic and Content analysis examines narrative materials by breaking text into smaller units and analyzing them through descriptive treatment. Content analysis can allow for adopting qualitative data analysis while quantifying it, using a descriptive approach in data coding and interpretation. On the other hand, Thematic analysis offers a more nuanced, detailed, and detailed account of data. Both methods offer valuable insights into narrative materials (Newman, 1998).

By describing and organising the information in great detail, thematic analysis can be recognised as a powerful method for analysing and discovering themes in research approaches such as qualitative data analysis (Braun and Clarke, 2006). Despite disagreements on its methodology and definition, current investigations have presented incredible insights into thematic analysis approaches. According to Vaismoradi (2013), thematic analysis is a descriptivequalitative method of data analysis. He also explored and outlined the distinctions between thematic analysis and content analysis.

The processes of data analysis in thematic analysis involve familiarizing with information and data, generating codes, searching for patterns, and reviewing themes, and finally, academic reports could be drafted. The similarity and differences between these two analysis approaches are shown in Figure 8 (Fellows & Liu, 2008):

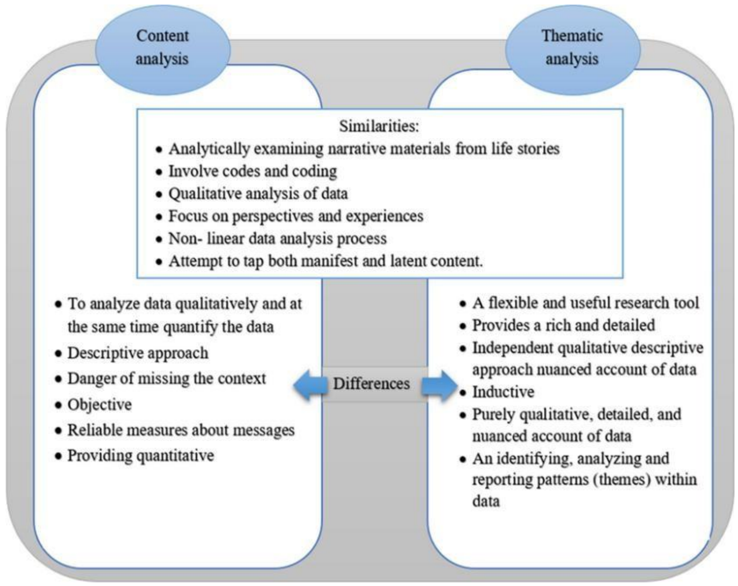


Figure 8 The similarity and differences between thematic and content analysis

Following the appropriate data analysis and based on the nature of the research by conducting 38 semi-structured interviews, this study was adopted thematic analysis for analysig data.

3.8.4 Critical review of literature

The research team should be conducted a systematic and reproducible literature review, synthesizing global scholars' work. It would be more beneficial if the researcher uses useful online services such as Science Direct and Google Scholar, which offer wider range of referenced, as recommended by Fink (2013). This research also used Fink's (2013) guide for conducting an effective literature review involvesthe following steps: first selecting a study question followed by selecting bibliographic databases, then applying practical screening criteria, conducting the review, and finally synthesizing the findings.

In this study, the researcher reviewed a wide range of peer-reviewed articles, recent conference papers, and reference books focused on significant keywords such as "industry 4.0 technology", "Internet of Things", "construction industry", "infrastructure sector", "building information modelling (BIM)", and "smart construction system". So, for this reason, the exploratory research study was conducted utilising these main keywords. The researcher also used Google trend data to refine academic publication search criteria. Datapoints were adjusted proportionately to query time and location, as shown in Figure 9.

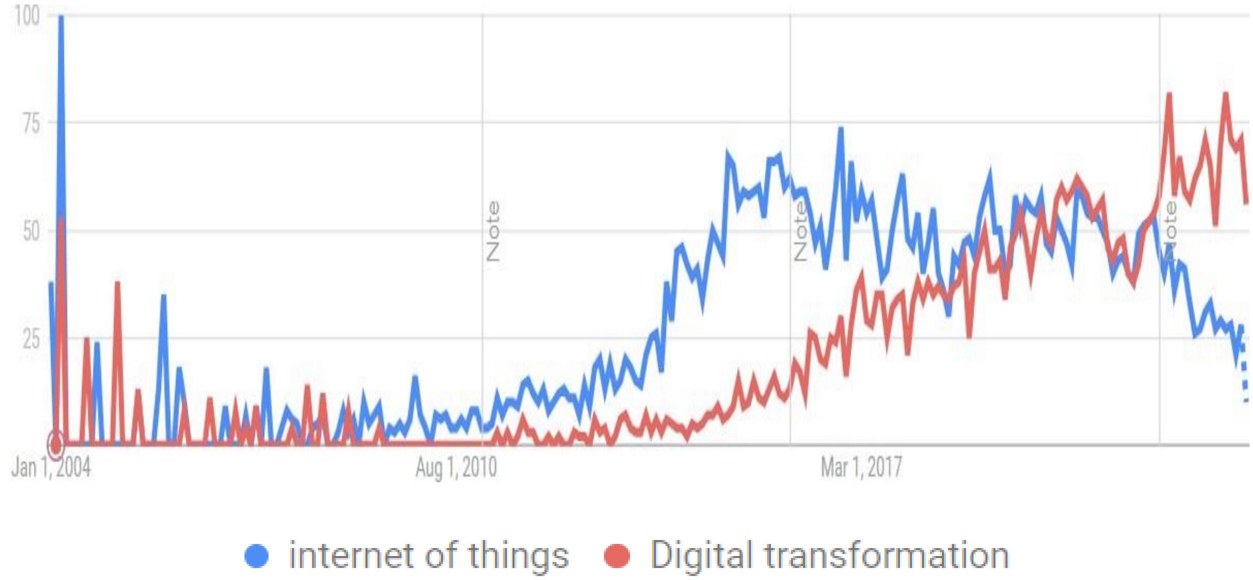


Figure 9 Growth in search popularity for "Internet of Things" and "digital transformation in the UK

Briefly, Figure 9 shows the growth in search popularity for "Internet of Things" and "digital transformation" in 2010, in the UK. This research study adjusted the literature review criteria to include publications from 2010, reflecting the trend's relevance in 2010.

This study selected relevant literature and followed White and Marsh's (2006) guidelines for conducting systematic content analysis in order to create themes on the Internet of Things (IoT) and industry 4.0 technologies. Also, the concept mapping method is employed to graphically conceptualize knowledge, and Microsoft VISIO software is used to create visual diagrams for a better understanding of the data. The process aimed to provide a comprehensive understanding of the research aim and objectives.

3.8.5 Quantitative data analysis

If qualitative data analysis is identified by analyzing the text from the participant's interviews, quantitative data analysis will deal with the numbers and statistical data that employed in a questionnaire survey. According to Saunders et al. (2012), some of the significant used techniques in this approach are including as, Factor analysis, Chi-Square analysis, Mann-Whitney analysis, T analysis, Correlation analysis, and so forth.

For instance, if two variables are calculated and connected to the probability, the researcher shall utilise the chi square test. So, it could be stated that there is 95% certainty that the relationship between both variables would have not occurred by chance alone with a possibility of 0.05 or less. The T test can compare the differences in two independent groups by using a measure of the scores. The T test utilises a measure of the scores for comparing differences between two sets of groups that are independent. This test aims to determine if the two independent groups differ from one another or not.

So, a large T statistic with an approximate probability of less than 0.05 indicates that there is a low possibility of any difference between these two independent groups. The Mann-Whitney test is used to examine if there is the possibility that the values of ordinal data variables (for two independent groups) are totally different from one another. By using this test, the researcher will have the ability to compare the medians and means of two independent, potentially non-normal distributions. Also, it will be employed if the independent group T testassumptions are not satisfied (Saunders et al., 2012).

Saunders et al. (2012) stated that the process of anylising quantitative data are including the assessment of the raw data, transfer the data, process the data, interpret the data and finally complete the data analysis. Creswell et al. (2009) suggested that the numbers and figures of the data collected from surveys will be analysed using inferential or descriptive statistics. For presenting quantitative descriptions in an understandable format, descriptive statistics are implemented. Also, it can be used to identify the central tendency of the data due to offer a general impression of the data. Descriptive statistics can be suitable for an initial description of the data and includes the median, standard deviation, and average (mean).

On the other hand, inferential statistics or advanced analysis will look at the immediate data beyond the central tendency and can be used to examine, differences, trends, and relationships within the numerical data. Also, it can allow the researcher to test the data for the strength of the relationships between variables.

According to Saunders et al. (2012), two different types of data such as parametric and nonparametric data can be analysed as an inferential statistic. So, parametric tests will provide opportunity for researcher to make assumptions about the entire population. On the contrary, non-parametric tests are unable to represent population-level assumptions. So, the most pertinent test must be chosen by the researcher for the purpose of the study in order to address the research questions.

Also, Creswell et al. (2009) stated that there are four levels of measurement that will influence the type of analysis are including the Nominal, Ordinal, Interval, Ratio. According to Creswell et al. (2009), nominal is described to quality more than quantity. As a matter of naming distinctions, such as 1 may refer to male and 2 may refer to female, a nominal level of measurement is determined. In addition, ordinal can be approached to the order in measurement. An ordinal scale can provide nominal information. The Low, medium or, high are the examples of ordinal levels of measurement. Interval level of measurement can provide information for researcher about the order and indicate equal intervals. As an example, an interval scale would be apparent if the gap between 1 and 2 was equal to the distance between 7 and 8 on a 10-point rating scale.

A scale with an absolute zero, or a point where no quality is being assessed, is referred to as a ratio. Utilising a ratio level of measurement enables comparisons such as being twice as high, or one-half as much. So, because of the nature of the research study, quantitative analysis was not considered in this research as a data analysing technique. The process of methodology that adopted in this research is shown as figure 10 and 11.

3.9 Summary

Creswell et al., (2009) asserted that one of the crucial components of every research project is data analysis, which enables the researcher to review and explore the gathered data and form conclusions. So, the next step of the research study will be analysing the data.

This chapter explains the research methodology used to gather and analyze data for the investigation. Utilising (Creswell, 2013) method for qualitative data analysis, a 5 step procedure was employed to assist with the data analysis, including the interviewee's audio transcription, transcript preparation, transcription literative review, coding, and themes generation.

White and March (2006) provided useful guidelines for qualitative content analysis, providing the iterative review could be helped understand interviewees' points, extracting issues and themesrelated to drivers and challenges of the research study.

Methods included in this research study are a critical review of literature, qualitative methodsby using semi-structured interviews, analysing of the data by using thematic and content analysis. Considering the pragmatic research philosophy that was used in this research study, these methods allowed flexibility in data collection based on the research's nature.

The researcher in this study analyzes literature and interviews findings to understand the impact of implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction industry, focusing on drivers, barriers, and key influencing factors. This study Utilized the data to develop a framework for implementing the Internet of Things (IoT) in the Uk construction sector. By considering to meet the aim and objectives the process of methodology that adopted in this research is shown as figure 10 and 11.

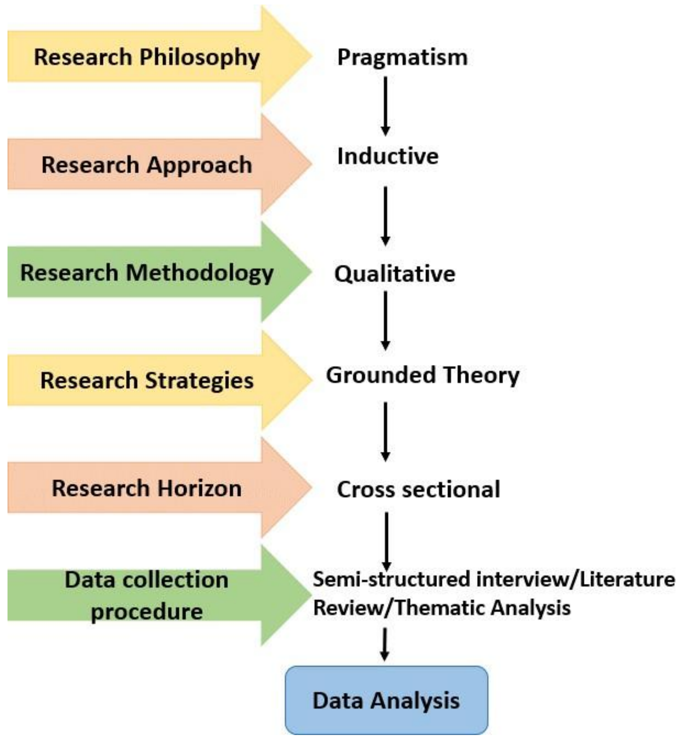


Figure 10 Research Plan

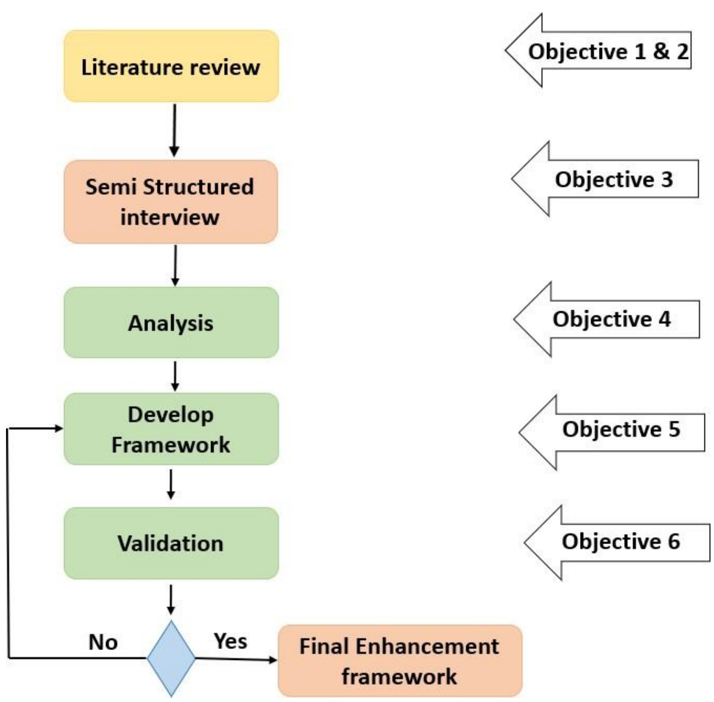


Figure 11 Research Road Map

Chapter 4. IoT adoption in the construction industry

4.1 Introduction

This chapter explores the adoption of implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector, focusing on the process of embracing new solutions that could impact the productivity of organisations.

This chapter analyzes the findings obtained from the literature, also complemented by 38 semi-structured interviews with construction professionals in the construction sector. Then, thematic analysis generates themes, revealing strong evidence of typical smart tools and technologies such as the Internet of Things (IoT) applications in the UK construction sector.

In this chapter, the following sections will be presented including examining the current digital tools integrated with the Internet of Things (IoT) applications in the construction sector, then, evaluating the app user's behavior, and finally, discussing the possible areas of adopting and implementing industry 4.0 technology such as the Internet of Things (IoT) in the construction sector.

4.2 Ustilising smart technology

Liu et al. (2017) surveyed the New Zealand construction industry, highlighting the most common smart devices used by the company's employees, finding that iPhones were the most commonly used mobile devices, followed by iPads. Also, Android phones and tablets are rankedin the next place. However, wearable devices were not widely used, with only 1.42% of employees considering using them, as seen on Table 2 by Liu et al. (2017):

Table 2 Smart tools utilised in the construction industry (New Zealand)

Devices	Response Count (from 141 respondents)	Response percentage
iPhone	105	74.47%
iPad	56	39.72%
Android Phone	70	49.65%
Android Tablet	30	21.28%
Tablet PC	23	16.31%
Windows Phone/Tablet	7	4.96%
RFID	3	2.13%
Wearable Devices	2	1.42%
Blackberry	1	0.71%

By considering the most common smart tools from literature in the construction industry and data collection of the 38 semi-structured interviews with the construction professionals in theUK construction sector, it will be revealed to add five new categories in the construction industry including Drones, GPS, smart boards, security cameras, sonar and sensors, and laser equipment. These additions will enhance the existing knowledge of the UK construction industry, as shown in table 3.

Table 3 Smart devices utilised in the UK construction industry

Smart devices	Out of 38 interviewees	Total response percentage
Smartphones	36	94.00%
Tablets	30	83.00%
Wearable devices	3	7.00%
Unmanned devices	6	13.00%
Smart boards	3	6.00%
Sonar surface	2	3.00%
GPS + Equipment	2	3.00%
Security cameras	2	3.00%

According to one of the interviewee's responses, non-aerial Unmanned devices or Drones could be adopted in the construction sector, particularly the places that will be hazardous, and challenging for humans to access it:

“Our current project is to maintain a historical tower; the management team decided to buy a **Drone** that could be connected to the Internet of Things (IoT) applications to monitor the current condition of the structure properly and also make the considerable reports with benefits including capturing high-quality images and films, accessibility on any time, fast transferring the data and information, **reduce the risk of falling from height**, live streaming, and so on. So, using this smart technology in the construction sector can increase the ability toaccess the places that could be hazardous or difficult for employees to access it" (UK-INF-031).

Following using the smart technology in the construction sector, some intervieweeshighlighted using the smart board as follows:

“…. absolutely using **smart board.** The smart board app allows users to view and **share their activities on the board.** Users can delete or add items without notification, but when talking on the phone, they can capture their actions and send them as PDFs or any other common types of files. Also, they could invite others or share the document with others” (UK-INF-017).

Also, he claimed that based on the nature of the construction job requiring information exchange, revieing and analysing data, attending online meeting, monitoring the job site etc., using this application integrated with the internet connection could increase the productivity of the company. Actually, smart boards enable sharing of information during meetings by allowing network connections to access drawings and share relevant information with others.

The UK-INF-026 interviewee highlighted the use of sonar surfaces to improve health and safety and eliminate hazards in construction projects. Although a direct quote is not provided, the sonar surface could be used to evaluate deep water circumstances without individual diving, thereby improving health and safety. In order to implement smart metering approaches, GPS has been integrated into existing equipment, as one of the interviewees presented:

“If our project manager has the ability to monitor the concrete mixer by using the **GPS** and

Internet of Things (IoT) applications when he left the batch, he can manage the job properly inan efficient time” (UK-INF-020).

Also, it could be great but costly if we could embed **GPS** to all our mobile equipment such as lorries,shovels, scissor lifts, forklifts, and so on. Actually, project manager by using the Internet of Things (IoT) applications could monitor and control the specific amount of equipment that willrequire for the job on site as well as update the inventory in our construction company” (UK- INF-034).

“Implementing the **GPS** could be so easy due to the installation of a SIM card and additional hardware. Then, capturing information and employing it. However, in terms of usability, the more difficult an implementation, the more likely it is to fail, especially in the construction industry” (UK-INF-001).

The most widely used smart device in the construction industry is the smartphone, with 100% of interviewees using them in their organizations. In general, smartphones are the primary smart device used by 89% of all respondents, followed by tablets and drones.

Liu et al. (2017) found that wearable devices in the New Zealand construction sector have low adoption, with just 1.43% of respondents using them. Also, only 14.2% of UK interviewees utilise these devices, however, their expensive price and lack of widespread adoption, such as smart helmets for visualisation, resulted in their under-adoption. One of the interviewees highlighted as:

“I have tried various VR applications, VR is a reasonable experience appealing to geeks, but it lacks communication and isolating capabilities. It is difficult to discuss with others what you can see, making it an **isolating experience**” (UK-INF-014).

4.3 Application user behaviour

According to Silverio et al. (2018), a major discrepancy exists in the literature considering the proper naming convention for mobile devices, such as smartphones, wearable, and tablets named Mobile apps, offering portability and addressing the naming convention. This discrepancy identified the significance of understanding the naming convention in the context of mobile devices. Developing a mobile app is essential for organizations, as they require particular websites and apps. Lim et al. (2015) found that users search for apps for specific information and entertainment, followed by task completion. The study examined typical app usage without focusing on specific industries. The major aim of downloading apps from various platforms is entertainment, resulting in the possibility to generate distractions at the workplace.

The user profile will significantly impact the usage model on general portable smart devices. Yang et al. (2015) claimed that heavy mobile data users contribute to 88% of mobile data traffic, with 1% of the population using apps with insufficient features, slow performance, difficulty, or malfunction. This section discusses app user behaviors in mobile smart devices, highlighting the importance of considering variables like data usage and application usage for construction organizations.

Lim et al. (2015) stated that app abandonment is the most crucial reason. Significant reasons for app abandonment include lack of need and becoming bored. Other factors include app crashes, insufficient features, slow performance, difficulty in use, andmalfunctioning functionality.

4.4 Areas of implementing smart technology

Chen and Kamara (2011) developed a framework for information management based on construction sites, focusing on users and construction data. However, the framework overlooks the autonomy of smart devices and shows smart devices as a dependent factor on users, as seen in Figure 12 by Chen and Kamara (2011):

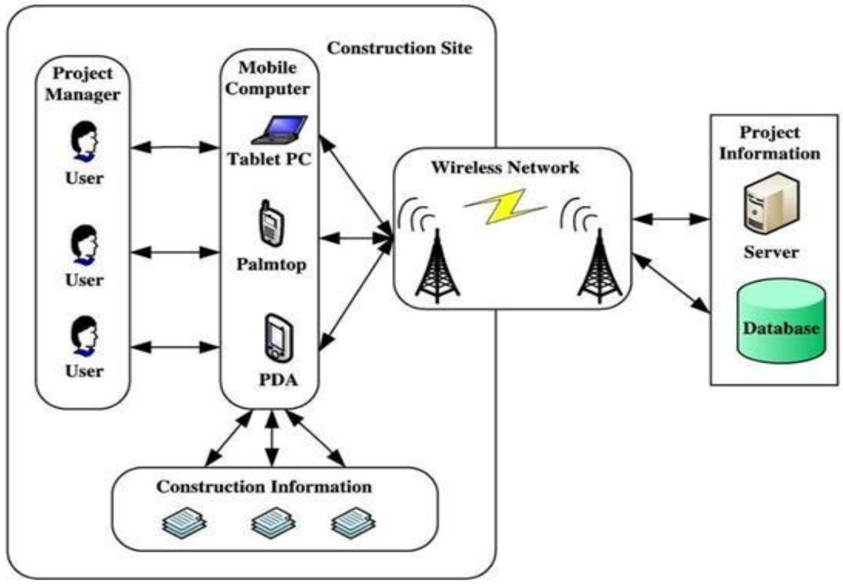


Figure 12 Framework for using mobile computing for information management on construction sites.

A smart device could be identified as an autonomous electronic device that connects to other devices wirelessly for exchanging data and information. The definition of smart devices and mobility among them were not present when Chen and Kamara (2011) developed their framework. The recent application of smart devices is crucial for the Internet of Things (IoT), a network connecting uniquely through computing devices (Miller, 2015). Table 4.3 displays qualitative data categories sorted by appearance. Data analysis extracted from the construction professionals in the UK construction sector identifies various utilisations, including data capturing, smart metering, site supervision, data exchange, material management, and contextual data request. The themes have the same identification but differ in implementation levels.

Utilisations	**38 interviewees %**
Data capturing and display	70%
Data exchange	47%
Site supvervision	29%
Contextual data request	22%
Smart metering	4%
Material t management	6%

Table 4 Utilisations of smart devices in the construction industry

Table 5 displays UK construction sector professionals' responses, with interviewee numbersidentified throughout the sections and consistent with other investigation chapters.

Interviewee Code	Data capturing and display	Data exchange	Site supervision	Contextual data request	Smart metering	Material management
UK-INF-001	x	x	x			
UK-INF-002	x		x	x		x
UK-INF-003		x		x		
UK-INF-004	x				x	x
UK-INF-005			x			
UK-INF-006		x		x		
UK-INF-007						
UK-INF-008	x					
UK-INF-009						
UK-INF-010						
UK-INF-011			x	x		
UK-INF-012	x					x
UK-INF-013						
UK-INF-014		x				
UK-INF-015			x		x	
UK-INF-016						
UK-INF-017						
UK-INF-018	x				x	
UK-INF-019						

UK-INF-020		x				
UK-INF-021						
UK-INF-022	x			x		x
UK-INF-023						
UK-INF-024						
UK-INF-025		x				
UK-INF-026						
UK-INF-027					x	
UK-INF-028						
UK-INF-029	x	x				
UK-INF-030						
UK-INF-031			x			
UK-INF-032	x				x	
UK-INF-033						x
UK-INF-034						
UK-INF-035	x					
UK-INF-036						
UK-INF-037					x	
UK-INF-038			x			

Table 5 Utilisations obtained from the UK interviewees

Following the below discussion, data collection sorted smart tools and technologies usage by relevance, based on interviewee percentages, and classified by category usage.

4.4.1 Data capture and display

“Data capture and display” received the highest comments in the interviews obtained from the construction professionals in the UK construction sector, discussing smart devices' implementation for capturing, storing, monitoring, and editing data and information. Based on the respondent from the interviewees, UK construction professionals for capturing and displaying data primarily use smartphones and tablets for job site tasks like photographic reports, taking notes, reading drawings, scheduling meetings, and communications. For example, by using various software and applications such as Microsoft Office products including MS Project, Excel, and Outlook they can send, receive, monitor, and control any data and information regarding their planning and scheduling integrated using IoT in their work area.

“Smartphones are frequently used for **taking photos for effective reports**, requiring a registry for organized information” (UK-INF-012).

Also,

“Utilizes the camera of my smartphone for daily reports, **sending images** via email, and downloading to a computer for daily report creation” (UK-INF-015).

Furthermore, one of the UK interviewees highlighted smartphone's usefulness for requesting information:

“Smartphones as a significant part of smart devices in the construction industry will focus on **accessing valuable data and information**, making them useful tools” (UK-INF-032). Additionally,

respondents stated that we can deploy smartphones to visualize job site drawings:

“I do not need to keep a printed drawing in my pocket, I just **take a picture** and keep it with myself whenever I need it” (UK-INF-020).

Also,
“Upon arrival at the project, I used Revit to modify drawings, export them to PDF format, and

easily open them onsite. No need for printing drawings” (UK-INF-038).

Unmanned Aerial Vehicle (UAV) or drone technologies are growing exponentially and becoming more interesting in the construction industry. Future expectations involve building assembly using UAVs, enabling more efficient and cost-effective building construction (Goessens et al., 2018). Interviewees stated that UAVs are primarily implemented in construction organizations for client demand, accurate data capturing, marketing improvement, and increasing health and safety. The decision to implement smart devices like drones will be depended on the organization's nature, culture, and management.

“The **drone** can scan tunnels easily, and completes a survey with one buzz, ensuring thoroughness” (UK-INF-002).

Briefly, Drone surveying could be a crucial sub-category, as intelligent machines become more available, assigning tasks to unmanned devices such as robots based on organizational cost and culture.

4.4.2 Communication

Communication is crucial for addressing construction industry challenges. Industry 4.0 technologies such as the Internet of Things (IoT) could enhance communication, increase information exchange, and enhance efficiency in site inspections (Kamblea, 2018).

The Internet of Things (IoT) as a significant pillar of the industry 4.0 technologies could facilitate information exchange through calls, emails, management and design apps, and chats, utilizing various media such as reviewing construction manuals, requesting quotation, sending construction photos, reviewing and designing drawings, and making proper reports. Based on the comments of interviewees, construction organizations are required to provide cloud computing systems for project storage and sharing.

“...... requesting quotations, chatting, finding the locations, reviewing construction M&E design, and messages for recall. In order to **use and access the information** anywhere and anytime, it would be beneficial for the company to present the cloud computing systems for projectstorage and sharing” (UK-INF-011).

The construction industry exhibits the highest level of mobility, decentralisation, external collaboration, and digital media creation. Smart tools in the construction industry could facilitate the exchange of information, enabling workers to share and exchange the relevant data and information of the project (Waidyasekara, 2021; Jung, 2021; Craveiro, 2021).

4.4.3 Site supervision

Site supervision significantly impacts construction project performance and efficiency. It is essential during the operation stage of the construction, using smart technology such as the Internet of Things (IoT) for event creation, staff tracking, project monitoring, meeting coordination, facility management, and security cameras real-time monitoring. Smart boards are smart tools that could facilitate information exchange during meetings. For example, by using RFID tags, companies can track their staff at any time. Also, by conducting CCTV in different places, they can monitor the workers' health and safety on construction site or by using GPS, they can track their construction vehicle easily. Construction organization in the construction sector could purchase particular applications or software for smartphones and tablets to monitor and control construction project activities, as per the interviewee's statement:

"In our company we have got an application that could **monitor and manage** work plans, sends activities to other smart devices, and provides live progress reports with attached photos" (UK-INF-003).

Also,

"We registered in a useful software named Procore as construction project management software, every morning our manager allocated the particular tasks to each of the employee to complete. We can access this software on our smart devices. Not only my manager can monitor and access the tasks, but also other employees can access such information as well. However, only my manager can delete or add tasks. This useful software could facilitate the **access and monitor** to construction information immediately." (UK-INF-033).

In addition, other Interviewees mentioned that using smartphones could be beneficial for live progress activities visualization by security cameras.

“Smartphones by connection to security cameras associated with the Internet of Things (IoT) applications enable **remote access to manage project activities** even from home, allowing project managers to monitor and control the construction project remotely” (UK-INF-021).

Also, other benefits of using industry 4.0 technology such as the Internet of Things (IoT) in the construction activity of the construction sector, as per interviewees mentioned include better management of the timesheet, increased workforce productivity, inventory and material monitoring, and reduce liability and risks.

In summary, adopting and implementing the Internet of Things (IoT) applications integrated with smart devices could contribute to site monitoring and supervision activities, such as security monitoring, meeting coordination, staff tracking, and project inspection.

4.4.4 Contextual data request

A data request is considered contextual when it presents the context of the request to offer relevant data and information and some of the interviewees highlighted using smart tools integrated with the Internet of Things (IoT) to receive geolocation data and information for their construction projects:

“By using the Google Earth application on our smart devices such as Smartphones or tablets, we could **visualize** road points and terrain-related information” (UK-INF-029).

Also,

“GPS is used for our road project marking, while smartphones are used for manuals and answering queries on the job site. Road signs are also marked using GPS” (UK-INF-010).

Following the interviewees comments, construction professionals could request GPS information based on project type and location to access relevant information on their smart devices such as smartphones. This efficient approach improves user experience when searchingmanuals on job sites. Also, geolocation could be utilised in road projects for better information retrieval.

4.4.5 Material management

Materials management can be recognised as the function to coordinate activities such as purchasing, transferring, and controlling materials to provide optimal service at minimum cost.

Material management involves complex operation activities like planning, design, and logistics for material movement and supply chain components (Jung, 2021). Employees also could be able to monitor and control the inventory by using particular software and applications integrated with the IoT on their smart devices such as smartphone and computers. For example, by using software such as MS Project and Excel, employee could monitor and track the material shortage, sending purchase order and receiving the invoice through using Outlook, accelerate productivity and performance on site activities to deliver the project on time within the budget.

This research finds interviewees utilising smart devices such as smartphones and tablets integrated with the Internet of Things (IoT) for material-related information exchange, inventory creation, and material requests.

“Microsoft applications such as the Outlook allows employees to **send and receive materials quotes and information**, control and receive them via email or phone, ensuring efficient and accurate resource management” (UK-INF-037).

Furthermore, Interviewees mentioned that barcoding can be employed for equipment tracking and faster accessing information:

“Following the installation of the Mechanical and Electrical (M&E) products in our project, we can easily use the barcode to **achieve the relevant information** about the product, by scanning the barcode and using the installed application in our smartphones integrated with the internet connection. This information allows clients or managers to identify the manufacturer, installation date, replacement date, cost, and other useful information in case of a breakdown” (UK-INF-022).

Additionally, researchers are attempting to convince the construction organization stakeholders to adopt and implement Unmanned Aerial Vehicles (UAVs) to automate construction industry processes, such as assembling prefabrication products. This trend could also highlight the future of adopting robotics in construction, using robots to provide a more automated approach to controlling and monitoring materials and inventory.

By implementing robots in the construction stages, particularly in the operation phase, future expectations for the construction industry could include increased efficiency and improved safety in material management, as one of the interviewees highlighted:

“**Robots** are increasingly utilsed in pipelines and harsh environments, replacing humans in tasks like drones and pipelines” (UK-INF-001).

In summary, following the respondent's adoption of Internet of Things (IoT) applications in the area of material management in the construction sector, this smart technology is utilized in construction projects to exchange material-related data and information, track equipment, and retrieve information faster. Robots could be innovative milestones, particularly in harsh and hazardous environments. With decreasing technology prices, UAVs are being investigated for faster and more efficient prefabrication assembly.

4.4.6 Smart metering

A smart meter is "an electronic device that monitors and records electric energy consumption and communicates it daily to utilities for monitoring and billing". Academic literature, such as Wen et al. (2018), discusses smart meters for electricity distribution and management.

Also, interviewees claimed that smart metering involves using smart devices integrated with the Internet of Things (IoT) applications to gather information and data on construction job sites, allowing for monitoring, analysis, and improvement of processes relying on it:

“We are now implementing hardware installations on types of equipment that could connect to the cloud computing system, allowing us to **track terrain and equipment movement**. This useful information is being uploaded to our software for efficient management” (UK-INF-028).

So, it could be concluded that construction organizations have integrated industry 4.0 technology such as the Internet of Things (IoT) into pre-existing equipment, enabling them to monitor and track data and information and receive accurate metrics like compaction level of terrain.

4.5 Summary

This chapter examines the Internet of Things (IoT) adoption findings in the UK construction sector, analyzing 38 semi-structured interviews and literature review to support findings. Construction professionals in the UK i construction sector employ various smart tools integrated with the Internet of Things (IoT) applications, including security cameras, sonar surfaces and sensors, drones, GPS, tablets, smartboards, and smartphones as the main one.

The Internet of Things (IoT) applications can be utilized in various construction sector areas, including data capturing, site monitoring and supervision, inventory and material management, communication improvement, contextual data request, and metering. 69% of interviewees stated using the Internet of Things (IoT) applications for data capturing, while 46% of respondents utilising them for communication improvement. Further comments obtained from the interviewees highlighted integrating GPS sensors in equipment and also adopting smart metering could improve the productivity of companies.

This chapter explores Internet of Things (IoT) applications adoption in the construction sector and discusses key drivers for implementing them, aiming to understand the industry's overall adoption of smart technology.

Chapter 5. Drivers to implement IoT in the UK Construction industry

5.1 Introduction

This chapter explores the drivers and barriers to implementing industry 4.0 technologies particularly, Internet of Things (IoT) applications in the UK construction sector, based on data from 38 semi-structured interviews with construction professionals in the UK. The findings are compared to relevant literature and are grouped into internal and external drivers. This chapter discusses drivers such as environmental protection, productivity, corporate transparency, mobility, management, health and safety, communication, stakeholder satisfaction, procurement, and competitive advantage. Most of the recommended drivers are highlighted in section 5.3, providing an overall discussion of the chapter.

5.2 Drivers for IoT implementation in the UK construction industry

This section explores the drivers for implementing industry 4.0 technologies particularly, Internet of Things (IoT) applications in the UK construction sector, through a critical review of the literature and qualitative content analysis. Interviewees were questioned about the factors that would encourage or promote the utilisation of Internet of Things (IoT) applications in their organization. The themes identified include managerial, economic, and corporate drivers, with sub-themes such as management, corporate transparency, communication, health and safety, productivity, environmental protection, mobility, procurement, competitive advantage, and stakeholder satisfaction. The themes that resulted from a qualitative analysis of the data collected are presented in Table 5.
Also, the interviewees' findings about the drivers were divided into two categories: internal and external. While internal drivers will directly affect the workforce, external drivers will impact the organization's external environment. The interviews are recognised by the interviewee codes, which are those depicted in chapter three. As a result,Table 6 presented the percentage of the number of interviewee responses throughout the research study. The interviewers' most common suggestion for a sub-theme or motivator was productivity. So, we employed the subject of productivity in our research to examine critical factors including time, cost, quality, and efficiency throughout the UK constructionsector.

Table 7 represents the responses received by interviewees during the interview process. All participants in the interview provided valuable and valid answers, confirming data saturation and preventing further interviews. The following sections discuss the drivers obtained from data collection and analysis, sorted by relevance and percentage of interviewees mentioning each driver.

Drivers	**Total Response percentage (out of 38)**	**Total response count (out of 38)**
Internal drivers	95%	38
Productivity	45%	18
Mobility	39%	16
Communication	37%	15
Management and	14%	6%
procurement	14%	6
Health and safety	6%	3
External drivers	29%	12
Environmental protection	11%	5
Corporate transparency	6%	3
Competitive advantage	6%	3
Stakeholder satisfaction	4%	2

Table 6 Respondent rates for drivers of implementing IoT

Interviewee code	Communication	Mobility	Productivity	Management and procurement	Environmental protection	Corporate transparency	Stakeholder satisfaction
UK-INF-001		x					
UK-INF-004			x				
UK-INF-005	x		x			x	
UK-INF-006	x						
UK-INF-007	x						
UK-INF-008							
UK-INF-009		x					x
UK-INF-010			x				
UK-INF-011		x		x			
UK-INF-012	x	x					
UK-INF-013		x					x
UK-INF-014	x						
UK-INF-015		x	x				
UK-INF-016	x		x				
UK-INF-017					x		
UK-INF-018	x	x		x	x		
UK-INF-019		x		x		x	
UK-INF-020		x					
UK-INF-021	x	x	x				
UK-INF-022				x			x
UK-INF-023	x			x			
UK-INF-024		x					
UK-INF-025	x						
UK-INF-026	x						
UK-INF-027	x	x					
UK-INF-028							
UK-INF-029			x				x
UK-INF-030		x			x		
UK-INF-031	x						
UK-INF-032							
UK-INF-033				x		x	
UK-INF-034		x					
UK-INF-035							
UK-INF-036			x			x	
UK-INF-037	x						
UK-INF-038				x			

Table 7 UK inerview drivers

5.2.1 Internal drivers

Identified internal drivers including productivity, management, mobility, health and safety, and communication will directly impact the UK construction company's workforce. These drivers will encourage the implementation of advanced technologies such as the Internet of Things (IoT) in construction projects, resulting in time and cost savings, mobility improvements, and enhanced communication. The vital features of these drivers are explained in the following sub-sections.

5.2.1.1 Productivity

Productivity refers to using innovative and production methodologies that minimize waste, increase growth rates, and reduce resource use. In the construction industry, cost and time are the most valuable factors for measuring productivity (Müller, 2017). In this research, 39% of interviewees considered productivity as a driver for using advanced technologies such as Internet of Things (IoT) applications in the UK construction sector. Productivity is the strongest driver mentioned by interviewees, with 47% considering it as a driver for using Internet of Things (IoT) applications in the construction industry. The professionals in the construction sector have a strong understanding of productivity, as evidenced by the following quotes:

“It saves time and money since there are some errors that will cost money, such as printing several documents on various pieces of paper all over the place” (UK-INF-029).

“People responsible for maintaining universities, educational facilities, or infrastructure in the field of construction drawing benefit greatly from the simplicity of knowing a drawing's condition, and who is created ......which will be resulted to save time and money” (UK-INF-012).

“To reduce the time and lower the cost of constructing….” (UK-INF-035)

“Firstly, you save an incredible amount of time by avoiding the need to write information down on paper or by making information capture easier” (UK-INF-012).

“The main advantage of the Internet of Things (IoT) applications is flexibility with time. Overall, not only we can use advanced technology in the construction industry but also, we can use it in various industries to save time and money to improve productivity” (UK-INF-003).

Interviewees highlighted the importance of saving time and cost in the construction industry.

They also highlighted the productivity benefits of smart device implementation and data usage.

“In order to Improve construction productivity and production processes, utilizing these advanced technologies are required to save time and cost reduction” (UK-INF-030).

“The potential of using data, in my opinion, is what inspires me the most given its speedand productivity” (UK-INF-005).

In Summary, construction professionals believe that implementing advanced technology such as Internet of Things (IoT) could save time and cost, increasing productivity in the UK construction companies.

5.2.1.2 Mobility

Mobility could be identified as the ability to access data and information ubiquitously, particularly using portable smart devices like smartphones or tablets. These devices can process information as well as provide user mobility. According to Muller (2017), smart devices can increase employee mobility and the capacity for ubiquitous data access in the construction workplace. Following the data collected from the interviews, 52% of interviewees considered mobility as a driver for using smart devices, with 21 out of 38 considering it as a driver. The UK construction sector is particularly impacted by mobility, as evidenced by quotes from interviewees.

“Accessing information on a smartphone is similar to accessing it on a computer. So, implementing this on-site solution for server information or general knowledge by using this smart device connected to the Internet would be the best solution, as people on-site will not intend to find a suitable place first, and then turn on their computer to access the data” (UK-INF-022).

“Integrating Internet of Things and Smart devices such as tablet will allow employees to work from anywhere without the need to carry a computer. This allows for more flexibility and quality work, as users can perform tasks at any location without the need for a computer. This eliminates the need to carry a computer and allows for more work to be done at any time. For example, to check the emails that received from the contractors and Architects, reply to the request of the clients, or….” (UK-INF-008).

Also, smart devices associated with the Internet of Things (IoT) could present onsite model visualization, making it more comfortable to detect clashes and gain a better appreciation of a project, as mentioned by interviewees.

“On the job site, a smart device such as a tablet connected to the internet could be used to visualize a BIM 3D model, allowing for a better understanding of problems and clashes. This 3D model is similar to reality, allowing for accurate observation of real projects with tube clashes. This would help identify design or construction mistakes and provide a more accurate understanding of the project's progress” (UK-INF-025).

Model visualization can range from CAD drawings to Building Information Modeling (BIM), allowing construction workers to access data anywhere in the project. Also, Mobility drivers will include ubiquitous data access, increased workplace comfort, and better awareness of project issues by allowing workers to visualize Building Information Modeling (BIM) onsite. This technology not only enhances the overall experience but also contributes to a more efficient and effective construction process.

5.2.1.3 Communication

Murray, Dainty, and Moore (2007) defined communication as transferring messages from a sender to a receiver and understanding them successfully. Kreps (1989) divided communication into four levels: intrapersonal, interpersonal, small-group, and multi-group. Intrapersonal communication involves internal processes, while interpersonal communication involves interactions between two people. Small-group communication involves multiple people, while multi-group communication involves communication between various work groups.

In the construction industry, various communication levels exist, including intrapersonal, interpersonal, small group, and multi-group communication. Intrapersonal communication involves structural engineers interpreting architectural drawings, while interpersonal communication involves project managers and workforce interactions. Furthermore, small group communication involves employees within the same department, while multi-group communication involves teams from different organizations, contractors, and sub-contractor teams. Mass communication, introduced by Emmit and Gorse (2006), indicates significant messages sent to particular audiences, such as the Human Resources department (HR) and organizational employee members.

The UK construction sector respondents highlighted that enhanced communication can be identified as a top attraction for implementing cutting-edge technologies, particularly the Internet of Things (IoT) in any smart devices to improve the productivity of the construction businesses. For instance:

“The transmission process and quality are the primary drivers behind the implementation of technology, understanding where we make mistakes and how to correct them” (UK-INF-012).

However, the construction industry's communication process could more complex and accurate, actually, implementing smart tools associate with Internet of Things (IoT) can enhance communication and team collaboration. This could increase encoding efficiency, making smart devices a valuable tool for improving team collaboration and communication in the construction industry.

Furthermore, Smart tools using the Internet of Things (IoT) assist construction organizations in accessing encrypted files and videos, and visualizing drawings, enhancing communication techniques and mobility in the construction industry.

“Enhancing processes, communication, and team collaboration is crucial for this company. The main driver is to share work more effectively, as it would be easier to display on smart tools and devices” (UK-INF-014).

In the Construction industry, the key notion to improve communication is to implement and adopt Internet of Things (IoT) applications with smart devices, benefiting decision-makers. For instance, Cloud computing and RFID technologies automate processes, then transmit data between employees, making them efficient and attractive to organizations.

The construction industry has experienced significant changes in communication due to the advancements in Information Technology (IT). These changes have increased information processing speed, accessibility to the data and information, and improved management systems for impressive decision-making. Furthermore, Poor communication is primarily causedby the lack of support for adopting communication tools and technologies, which are related tosmart devices and the Internet of Things (IoT). Other organizational and social factors, such as technology malfunction, language barriers, lack of skills, and inadequate communication systems. Also, negative consequences of poor communication include time and cost overruns, rework occurrences, and conflict among construction parties (Kang, 2022; Waidyasekara, 2021)

Eventually, improving communication processes in construction organizations offer numerous benefits, especially in the project-based industry where stakeholders collaborate in unique geographic and economic conditions to build a project in a short time.

5.2.1.4 Management and procurement

According to Jung (2021), construction management involves various knowledge domains, including project integration, quality assurance, cost and time management, human resources, risk assessment and so on. These domains are essential for effective project execution and overall success in the construction industry.

Li (2020) argued that project management in the construction industry can be recognised as conducting initiation, planning management, performing, monitoring, and closing teamwork to achieve the ultimate goals of the project and meet success criteria. Furthermore, procurement involves obtaining goods, materials, and services for profitable and ethical operations. The subject of this discussion addresses how the project management and procurement processes of the construction industry are perceived by implementing smart toolsand technologies.
5 out of the 25 respondents noticed multiple elements of project management as driving forces for adopting smart technologies into their projects. For example:

“In a large project, using smart technology integrated with the Internet of Things (IoT) ensures constant communication and information sharing. This is especially important for my boss, whois in another city and doesn't visit daily. Some other employees such as engineering are also in that city, requiring constant interaction throughout the day” (UK-INF-030).

“I desire to have an internet connection and smart devices for scheduling, programming material requests, and organizing job site logistics. By using the apropriate app, I can easily accelerate the task to be done in an efficient time” (UK-INF-001).

“For implementing smart tools such as the Internet of Things (IoT), security management is crucial, as access to project cameras from a smartphone allows users to monitor and control activities. This integration of security and technology is essential for ensuring a secure project” (UK-INF-008).

The literature indicates a positive perception of smart tools in improving management concepts and procurement processes. According to Xu (2018), Construction workers in New Zealand perceived benefits such as more efficient documentation management, improved site reporting, proper employee timesheet model, and accurate price and change order tracking.

5.2.1.5 Health and safety

The construction industry, in comparison to the other industries, has the worst occupational accident record due to its complex, hazardous, risky environment, and decentralized nature. According to Ji (2022), studies aimed to reduce accident rates by examining typical behavior, extracting evaluable characteristics, or implementing new systems of approach.
These efforts aimed to improve safety and reduce the risk of accidents in the construction industry.

“Construction companies prioritize health and safety, adopting new technologies to help, monitor, and control health and safety as a priority. To ensure safety, companies prioritize smart tools and devices, connecting with the internet, and implementing safer methods whenever possible to control and monitor the workforce. This approach ensures that any unsafe practices are avoided, ensuring the continued success of construction projects” (UK-INF-002).

“The company prioritizes safety as the top concern, as we haven't had any serious issues such as dead workers in the last years. Safety is the most crucial factor, and we prioritize safety over cost and time” (UK-INF-038).

In a nutshell, health and safety are key considerations for construction businesses. This research suggests that large companies are more interested in improving, maintaining, and implementing health and safety rules, standards, and regulations as they have higher leadership and a greater ability to invest. This means that even if smart tools and technologies implementation costs are high, the company may still approve it if it increases and improves safety standards.

5.2.2 External drivers

In order to explore the external benefits of implementing the Internet of Things (IoT) integrated with smart tools and technologies, this section will present that the construction sector as a significant part of the construction industry will benefit from factors including corporate transparency, environmental protection, stakeholders' satisfaction, and competitive advantage in the external environment.

5.2.2.1 Environmental protection

According to Kang (2022), environmental protection aimed to conserve natural resources and the environment, reverse harming trends, and repair damage. One effective initiative is reducing workplace paper waste. So, implementing smart tools and technologies like the Internet of Things (IoT) can benefit environmental protection, although it is not the top priority in the construction industry. In this regard, some of the particular statements were extracted as follows:

"Buildings are designed to meet high-quality environmental standards, but this doesn't alwaystranslate to reducing paper usage. It's significant to consider the amount of paper needed for meetings and job site printing. It's crucial to consider the impact on the environment and theneed for sustainable practices" (UK-INF-031).

"Paper waste is a significant issue in construction business environments, as always it requires a large box of printed drawings, particularly in technical and architectural offices, both up to date and outdated. This paper waste can lead to garbage and cause environmental issues. The migration to utilise a smart world by using digital devices and Internet connection could be an interesting solution for reducing paper waste and improving the efficiency of projects" (UK-INF-012).

In this research, interviewees mentioned that smart tools and techniques enable document visualization, transforming the construction industry into more digital. It could be impacted when employees used design software such as CAD and Revit, and sent these documents by email to other parts of organisation for review and approval. So, adopting digital tools integrated with the Intenet of Things (IoT) will reduce paper usage, which is perceived as a driver for implementing devices like drawing visualization. Case studies showed successful reductions in paper consumption in construction companies through the use of tablets and other smart devices. Examples include Coddington's project, where a company went paperlessfrom beginning to end, and designed paperless processes using tablets loaded with cloud- stored drawing sets Coddington (2012).

5.2.2.2 Corporate transparency

Transparency in literature is identified as approachable towards partners, distinct communication exchange, and the perceived quality of shared data and information. Corporate transparency refers to the transfer of intentionally shared information within a corporate environment (Potosky, 2008).

“The solution for legal problems involves saving everything during the construction project, for instance, using an app such as Zoom meetings for group communication associated with an internet connection and using a tablet with an app for quality survey templates. Also, our company provides us a Doc Hub software, which means main stakeholders such as clients, architects, consultants, contractors, sub-contractors, etc. needed to upload their drawings, specifications, comments, and request for more information (RFI) on this platform to share and review the data and information. Thanks to the Internet of Things (IoT) that will be aimed to make the process more transparent and easier for review, comment, and feedback” (UK-INF-001).

Interviewees believe that using smart tools and technologies such as smart tools and technologies such as smartphones, tablets, and web-based software and application associated with the internet connection could increase company transparency. This is considered a way to improve employee file sharing, as guidance on corporate transparency suggests.

Corporate transparency is influenced by disclosure, clarity, and accuracy, as per Schnackenberg and Tomlinson's guidelines. Disclosure refers to the timely receipt of relevant information, which increases as stakeholders perceive it as more relevant and timelier. Clarity is the perceived level of comprehensibility and lucidity of data and information, which increases as stakeholders perceive it to be more understandable. Finally, accuracy is the perception that data and information are correct, which increases as stakeholders perceive it as more reliable. (Oesterreich, 2021).

Also, Tezel (2021) suggested that organizations could enhance disclosure by utilizing open data and information systems. By sharing particular data and information through the cloud system and approaching it via smart tools, construction companies could enhance their corporate transparency. Smart tools and technologies such as the Internet of Things (IoT) also enable historical communication tracking, enabling stakeholders to review previous decisions, discussions, and conversations during disagreements (Waidyasekara, 2021). As a result, corporate transparency ensures accurate, clear communication and information exchange between stakeholders in an construction project.

5.2.2.3 Competitive advantage

Competitive advantage can be recognised as a company's survival and growth in the market, and innovation in construction businesses increases their possibilities of survival and growth, as noted by Jolly et al. (2016). Competitive advantage was mentioned by some of the interviewees as a motivator for adopting internet of Things (IoT) and smart tools as follows:

“Companies face competition and must stay competitive. Smart technologies and particular gadgets provide a competitive advantage, and some companies implement them to stay ahead. As technology advances, others may feel pressure to follow trends” (UK-INF-029).

The literature highlighted the impact of implementing and adopting industry 4.0 technologies such as the Internet of Things (IoT) on an organization's competitive advantage, with effective implementation providing crucial advantages for increasing the productivity of the construction companies (KAPLIŃSKI, 2018).

5.2.2.4 Stakeholder satisfaction

In this research, stakeholder satisfaction will be examined as the achievement of project expectations in any construction project phase's performance. Actually, along with traditional measurements like time, cost, and quality, stakeholder satisfaction may be employed as a criterion for evaluating the success of a project (Guo, 2021; Cheng, 2020).

Interviewee (UK-INF-029) claimed that construction companies are utilising innovative technology in order to satisfy their customers: “Construction companies utiliseinnovative technology to boost client confidence. Adopting smart tools and techniques improves client-construction company relationships, benefiting all stakeholders through implementation”.

Stakeholder satisfaction could be measured or evaluated using a number of vital parameters that are presented in the literature. Ahmed and Kangari (1995) highlighted six variables for obtaining client satisfaction including time, client orientation, cost, communication skills, quality, and response to complaints. Time and cost are considered productivity drivers, while communication skills are communication drivers. Also, he claimed that Increasing communication and productivity between stakeholders is crucial for achieving stakeholder satisfaction. Leung et al. (2004) emphasized that management mechanisms like commitment and communication are more effective than project ultimate objectives such as time, cost, and quality.

Ultimately, implementing smart tools and technologies such as the Internet of Things (IoT) leads to increased productivity and improved communication among stakeholders, resulting in increased satisfaction.

5.3 Summary

This chapter explores the UK construction sector professionals' suggestions for implementing smart tools and techniques such IoT, based on qualitative data collected from 38 semi-structured interviews. The following drivers of implementing and adopting this innovative technology are discussed. This chapter discusses drivers such as environmental protection, productivity, corporate transparency, mobility, management, health and safety, communication, stakeholder satisfaction, procurement, and competitive advantage. The interviewees’ highlighted productivity as their primary incentive for adopting smart devices in construction projects, with majority of the respondents indicating productivity as anadvantage.

Interviewees emphasized the importance of mobility in accessing data and visualizing project information, with using smart tools and technologies being the second most significant benefit. The literature, as well as the interviews, claimed that smart tools and technology such as the Internet of Things (IoT) could completely revolutionise how construction employees share data and information. As a result, communication is a crucial factor that affects stakeholder satisfaction, corporate transparency, and mobility.

Following the next driver, smart tools and technology such as the Internet of Things (IoT) contribute to environmental protection in the UK construction sector by reducing paperwork in construction projects and identifying with numerous companies implementing paperless construction projects. The least discussed benefits of implementing smart tools and techniques such as the Internet of Things (IoT) in the construction sector include stakeholder satisfaction, competitive advantage, corporate transparency, and health and safety (less than 10% of the interviewees). However, these drivers presented valuable and reliable insights into the endless possibilities and motivations behind conducting and adopting digital tools and technologies.

In this chapter, the third research goal of this study, which is to examine the main drivers for applying smart tools such as the Internet of Things (IoT) in the construction sector, has been discussed. The principal challenges with adopting smart tools such as the Internet of Things (IoT) in the construction sector will be covered in the next chapter.

Chapter 6. Challenges to implement IoT in the UK construction industry

6.1 Introduction

This chapter discusses the significant challenges and barriers to implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector, based on 38 semi-structured interviews with construction professionals in the UK. The findings are compared to appropriate literature and based on participants' perceptions. Actually, the data analysis reveals the significant challenges in the construction sector for implementing the Internet of Things (IoT), categorized into three sections including technological, cultural, and economic aspects.

6.2 Challenges for implementing IoT in the UK construction industry

The three key challenges emerged from the interviews, which were grouped into economic, cultural, and technological. Table 8 highlights the three crucial challenges identified from the qualitative data analysis (38 semi-structured interviews) by applying to the UK construction professionals.

Table 8 Respondents challenges pecentage

	Total Response percentage (out of 38)	Total response count (out of 38)
Challenges	**responses)**	**responses)**
Economic challenges	65%	24
Cultural challenges	59%	22
Technological challenges	51%	19

The most participants (65%) out of the interviewees mentioned economic challenges. 59% of respondents suggested cultural problems. Finally, 18 out of the 38 interviewees identified technological obstacles. The next section outlines key challenges identified from data collection and analysis, sorted by relevance and interviewee percentages mentioned.

6.2.1 Economic challenges

Economic challenges and barriers are common issues in Information Technology (IT) investment. It is crucial to consider indirect costs, including human and organizational costs. The interviewers focused on cost as a crucial factor. To provide an understanding of the industry's perspective, many statements from the interviews have been included.

"The key obstacle is absolutely cost, as my supervisors may not be willing to pay for investing the advanced technology that could not be used based on accepting the future projects" (UK-INF-036)

"The significant concern is the high cost of developing these technologies, which could be a key challenge rather than an impossibility. The main concern is the potential for increased expenses" (UK-INF-009)

Kang (2022) highlighted the economic challenges will be identified as significant obstacles to implementing industry 4.0 technologies such as the Internet of Things (IoT) in construction projects, with upfront purchase costs and operating costs being major obstacles. Additionally, respondents claimed that one of the key variables in economic challenges is the cost of implementation and the size of the organisation.

"The company's risk is higher due to its small size and lack of experience in similar projects. While a larger project may absorb such costs, smaller projects require evaluating the cost-effectiveness of this tool. It could be risky for our company as a small and medium size enterprise (SMEs), which would be needed to employ the skilled employee in our projects" (UK-INF-034).

6.2.2 Cultural challenges

This section discusses cultural challenges and barriers identified through the data collection, focusing on the construction company's culture. Firstly, it is crucial to describe the context and features of culture within the literature. Culture can be defined through numerous dimensions, including achievement and ascription,universalism and particularism, internal and external control, and specificity and diffuseness.Also, collectivism, cultural tightness, individualism, cultural complexity are the four universal cultural aspects identified by Triandis (1994).

Cultural dimensions play a crucial role in comparing Information Technology (IT) implementation across countries. For example, power distance, a cultural variable, has an intense correlation with the acceptable and reliable implementation the IT systems. By distinguishing users and implementers, it assists with forecasting the successful outcome of implementation strategies. High power distance creates a society where those in positions of authority feel more distant and detached individuals, while low power distance indicates a closer, more befriended subordinate Griffith (1998).

Hasan and Ditsa (1999) indicated that successful IT adoption commonly occurs in low-power cultures. For instance, employees, students, and others in these cultures are more likely to report complaints and malfunctions to pertinent implementers. Additionally, students in low power distance countries are more innovative and trusting of technology.

So, it can be identified that cultural dimensions are crucial for the successful implementation of smart tools and technologies in the construction industry. Analyzing these challenges highlights the importance of identifying distinct cultural characteristics throughout the UK construction sector. Lack of leadership is mentioned by interviewees as a significant barrier to integrating smart technology such as the Internet of Things (IoT) into their construction projects. Also, in terms of lack of leadership, the respondents claimed that the company's decision-makers would be hesitant to embrace an unproven IT solution in order to minimise risks.

“Sometimes, a factor such as leadership is crucial for introducing digital tools and techniques in your construction company, however, it might be a big concern if the company's top-down leadership fails to encourage forward” (UK-INF-002)

“I work in a small construction company as sub-contractor, my boss and his boss are dependent on each other for funds to purchase advanced web-based technology for project development” (UK-INF-004)

Craveiro (2021) presented the advantages of improved organizational leadership, including greater monitoring and site inspection, increased client satisfaction, accurate documentation and better reporting, minimising risks. In an organisation, the level of leadership determines the direct link between the likelihood of managers embracing change and the likelihood of employees adopting innovative technologies. Construction businesses could more greatly understand their staff culture by comparing low-embracing companies to high-embracing ones. Companies with low embracing cultures should carefully measure the benefits of employees towards industry 4.0 technologies such as the Internet of Things (IoT) associated with smart tools, while high-embracing companies should desire deeper adoption. This chapter examines organisational culture, training and development, and other cultural issues related to the construction industry in order to discover solutions to these challenges.

Also, Organisational culture impacts professional goals, thoughts, and actions in the workplace, influencing task performance and resource allocation (Lok and Crawford, 2004). It was determined that 7 out of 38 interviewees, or 19%, mentioned organisational culture as an obstacle to using advanced technology such as the Internet of Things (IoT) in the construction sector. The interviewees presented the following comments:

“Resistance to change is a major issue in the construction industry, where professionals and responsible individuals prioritize delivering projects on time and under budget. This makes it difficult to sell new ideas to them, as they are not interested in new approaches” (UK-INF-025).

“The important barrier is transforming practices, creating a consciousness of improvement and people's willingness to change” (UK-INF-033).

Based on the following comments of the interviewees (43% of responses), staff training and development is crucial for implementing advanced technology in the construction sector, particularly in utilising smart devices. It allows construction businesses to maximize the benefits of these devices to improve productivity by reducing time and cost. Complex Internet of Things (IoT) systems, for example, may require employees to collect data in specific ways, reversely, causing the system to underperform or behave incorrectly. So, it is essential to understand employees' capabilities and adapt to new technologies to ensure the successful implementation of cutting-edge technologies such as the Internet of Things (IoT) applications in the construction sector.

“Our office staff consists of only three people in the age of twenties, with the rest in their late forties. This older age group is less enthusiastic about learning new technology, and lacking relevant experience and knowledge in implementing the new technology could adversely impact the productivity of the construction project" (UK-INF-030).

"I believe that personnel training may be challenging for those not yet prepared to understand the concepts, making it more challenging for them to comprehend the information" (UK-INF-016).

The possible lack of expertise and proficiency in new technology among construction workers is an important contributing factor to this issue. For instance:

"Making engineering professionals aware of the positive impact of technology in construction is crucial, encompassing designers and executioners. It is essential to clearly explain the benefits and challenges of implementing innovative technology in the construction industry, ensuring a clear understanding of its potential" (UK-INF-021).

Project location is another issue that was mentioned by the interviewees, for example:

"Implementing new technology on a jobsite faces challenges due to location, such as lack of internet, electricity, and other resources. Starting a project in a zone with no internet or signal can make it difficult to use advanced technology, particularly to share data and information. This could hinder the success of the project" (UK-INF-033).

The technical challenges in deploying smart tools and technology will be discussed in the next section.

6.2.3 Technological challenges

In terms of Technological barriers in the construction sector, three significant challenges in adopting the advanced tools and technologies are discovered including the inability to use smart devices, hardware and software incompatibility, and internet access limitations, as discussed by interviewees.

"Technical challenges include GPS accuracy, which is limited in urban environments. For example, approximately five meters location is insufficient for wind farms, as it is on the wrong side of buildings" (UK-INF-017).

"If our project manager has the ability to monitor the concrete mixer by using the GPS and

Internet of Things (IoT) applications when he left the batch, he can manage the job properly inan efficient time, however, because of the small size of our company we cannot access to such information" (UK-INF-021).

"In some cases, smart tools have limitations, with no keys, unlike computers with a full keyboard, large monitor, or even mouse. For instance, imagine you must work on complex BIM information, and these devices do not have the ability to implement the task. On the other hand, managing this job with your hand and simple paper to draw the 3D model is another limitation" (UK-INF-026).

Battery life is another issue in utilizing smart devices integrated with internet connection which some of the interviewee mentioned that as follows:

"For instance, you are always required to charge your smart devices. If you forget to charge them one day and it is not ready to use, you're left with nothing. Imagine you need to make some amendments to the schedule of the program by using your Microsoft Project and your tablet connected to the internet and then run out your battery. So, you must wait until you get back to the office to use your computer or wait to charge your tablet" (UK-INF-038).

"Battery life is one of the disadvantages of using digital technology such as tablets and smartphones, as they may run out of charge, making them unusable on the site. Computershave stable energy sources, while smartphones may run out of power" (UK-INF-009).

Elazhary (2018) highlighted that smartphones' battery life is one of the challenges on construction job sites. Also, hardware and software specifications change constantly, so, these limitations should be considered a significant challenge rather than battery life and GPS accuracy in the implementation of smart devices. Also, internet accessibility is another challenge in using smart technology in the construction job site that was suggested by the interviewees.

"Internet access is crucial for smart devices, as it allows for information exchange and communication. However, the availability of signals on smartphones on job sites may pose a challenge" (UK-INF-007).

"Making the internet connection faster and more reliable would be another improvement. As I work in a small company, we usually use our central internet connection when we work at the office. However, on job sites and locations where we do not have access to the internet connection, it could be a significant challenge, using our internet connection that may not be fast and reliable enough to transfer and receive our information, particularly when you should review the big files such as AutoCAD or Revit drawings. On the other hand, because of the small size of the company, they cannot provide fast and unlimited data usage for each employee to use it at job site" (UK-INF-006).

Also, security of the internet connection is another challenge that was presented byinterviewees.

"Sometimes we use our personal internet connection to share confidential data and information with other parts of the oraganisation. These personal devices may not be secure enough to avoid cyber security attack" (UK-INF-009).

So, implementing cyber security system as a significant part of Industry 4.0 technologies integrated with internet of Things (IoT) is recommended to share the information in the whole sections of the construction sector. Ultimately, usability is crucial for implementing smart technology such Internet of Things (IoT) in construction projects. The main features of usability include increased efficiency, effectiveness, and stakeholder satisfaction, which measure task completion and user experience.

"Platforms such as complex design programs that are not user-friendly could hinder users' exploration of new possibilities due to their old mindset, making them less open to updated software and challenges. This disadvantage can be attributed to the complexity of these platforms" (UK-INF-030).

"Our company installed a particular application on our tablets to write the report immediately after we did the job. While the idea is appealing, users often face login issues, lack of signal, or forget passwords. Additionally, they may need multiple attempts to access the system, leading to a lack of usage. As a result, most employees are reluctant in using the application and preferto write it down on a piece of paper" (UK-INF-001).So, previous experiences of interviewees with using advanced technology such as the Internetof Things integrated with smart devices reveal challenges in efficiency and stakeholders' satisfaction, hindering successful implementation.

6.3 Summary

This chapter has explored the pivotal challenges in implementing advanced technology such as the Internet of Things (IoT) associated with smart devices in the construction sector, categorized into economic challenges, cultural issues, and technological barriers. Economic challenges present the high cost of smart tools, investment issues, and cost of training, hiring skilled employees, and company size. Construction industry professionals emphasized the importance of company size in technology investment.

Small construction businesses may lack resources, while larger companies by getting more opportunities to work on multiple projects could allow the manager to better control projects and also improve communication between stakeholders and employees as a result of adopting and implementing industry 4.0 technologies. It is obvious that large construction businesses have larger budgets, making it easier to adopt and implement innovative and smart technologies. They may also have multi-city projects, encouraging and convincing them to adopt and implement innovative tools for their construction projects. It can be identified that the high cost of Implementation of Industry 4.0 technologies significantly impacts decision- making approaches in the construction industry.

It would be recommended by the interviewees that the Government could assist in this matter by funding the construction companies by investing in digital technologies or even providing untaxable scheme to buy digital tools and equipment trying to encourage the stakeholders particularly for the small and medium firms to purchase these smart technologies.

While cultural challenges address organizational culture in the construction industry. Kenny and Reedy (2006) defined an innovation culture as a mindset that creates and establishes values within a firm. This culture could improve the functioning of the firm, even if it conflicts with conventional behaviour.

To adopt this culture, Kenny and Reedy suggested three attitudes: shared responsibility, willingness to take risks, and stimulation of creativity. These attitudes will aim for the construction industry to succeed in adopting an innovation culture. Furthermore, Canalejo (1995) recommended adopting a creative organizational culture in the construction industry could be valued by focusing on client orientation, continuous improvement, overcoming challenges, objective commitment, and teamwork. Using these results from the literature, this study suggested addressing all dimensions of an innovative culture to foster a culture in the construction organisation.

Also, in terms of technological challenges, the implementation of smart tools in the construction sector is hampered by hardware, software, and technology limitations. According to Xu (2018) governance and leadership will influence decision-making in ventures, and construction industry organizations by adopting leadership toward innovation activities will receive effective management sponsorship for implementing new technological approaches. Interviewees suggested training for employees could be the key influencing factor to better understand and adapt to the new digital technology in the workplace.

Following the analysis of the interviewees, 59% of interviewees presented cultural challenges as the top challenges in the UK construction sector. Organizational culture could impact professional goals, and conscious and subconscious thinking, making it a significant challenge for the sector. Also, 50% of interviewees identified that to implement innovative technology such as the Internet of Things (IoT), technological challenges should be addressed in the construction sector including GPS accuracy limitation, poor usability of the digital technology,battery life, poor performance of the smart devices, and internet accessibility.

This chapter has highlighted the third objective of the research study which is to explore and examine the challenges of implementing the Internet of Things (IoT) in the construction sector. The following chapter will consider the key influencing factors for implementing industry 4.0 technology such as the Internet of Things (IoT) in the construction sector.

Chapter 7. Key influencing factors for implementing IoT application in the Uk construction sector

7.1 Introduction

This chapter discusses the key influencing factors (KIF) for the implementation of Industry 4.0 technology such as the Internet of Things (IoT) in the construction sector. The findings have been constructed on qualitative data collected through 38 semi-structured interviews with construction professionals in the infrastructure sector, analyzing their perceptions and comparing them to relevant literature.

7.2 Key influencing factors for implementing IoT application in the Uk construction sector

Key influencing factors can be described as the significant factors that ensure success for managers, leaders, or organizations, requiring special attention in managerial or enterprise areas to achieve high performance. These factors are crucial for achieving effective success and maintaining high-performance levels (Craveiro, 2021). The participants were questioned on the keyinfluencing factors (KIF) for implementing Industry 4.0 technology, specifically the Internet of Things (IoT), in the construction sector.

Table 9 displays qualitative data analysis that categorized the top five KIFs, ranked by the percentage of participants mentioned. By analysing 38 interviews with construction professionals in the UK construction sector, these factors will be revealed increasing employee training, enhancing leadership and managerial actions, funding the cost of implementing digital technologies, and improving technology awareness. Table 9 displays responses from the construction professionals in the UK construction sector, using interviewee codes from Tables 3 Also, table 10 displays individual responses from each interviewee.

Table 9 Response counts and rates for KIFs obtained from UK interviews

KIFs	Total Response percentage (out of 38 responses)	Total response count (out of 38 responses)
Leadership	36%	14
Staff Training	23%	9
Organisational Culture	21%	8
Technology Awareness	18%	7
Cost	15%	6
Company size	10%	4
Usability	7%	3

Table 10 KIFs obtained from UK interviewees

Interviewee Code	Leadership	Staff Training	Culture	Technology Awareness	Cost	Company size	Usability
UK-INF-001					x	x	
UK-INF-004							
UK-INF-005							
UK-INF-006	x						
UK-INF-007				x			
UK-INF-008							x
UK-INF-009							
UK-INF-010							
UK-INF-011	x						

UK-INF-012							
UK-INF-013				x			
UK-INF-014	x			x			x
UK-INF-015	x						
UK-INF-016						x	
UK-INF-017				x			
UK-INF-018		x			x		
UK-INF-019	x		x				
UK-INF-020	x		x				
UK-INF-021		x	x		x		
UK-INF-022	x	x	x		x	x	
UK-INF-023		x				x	
UK-INF-024	x						
UK-INF-025							
UK-INF-026	x		x				
UK-INF-027		x					
UK-INF-028							

UK-INF-029							x
UK-INF-030	x			x	x		
UK-INF-031		x					
UK-INF-032							
UK-INF-033						x	
UK-INF-034	x		x				
UK-INF-035							x
UK-INF-036					x		
UK-INF-037		x					
UK-INF-038				x			

The KIFs obtained through data collection are described below. The percentage of interviewers who mentioned each area is considered while determining the order of significance.

7.2.1 Leadership

Based on the interviewees' responses, leadership is highlighted as the most KIF, as it is crucial for the successful implementation of industry 4.0 technologies such as Internet of Things (IoT) applications in the UK construction sector. 47% of interviewees identified that leadership and managerial activity could be the first priority as an IKF. According to Xu (2018) governance and leadership will influence decision-making in ventures, and construction industry organizations by adopting leadership toward innovation activities will receive effective management sponsorship for implementing new technological approaches.

Implementing a new paradigm requires convincing decision-makers about its drivers and benefits, such as better client satisfaction, efficient documentation management, improved site monitoring, enhanced accuracy of reporting, and reduced risks through compliance reporting. Liu et al. (2017) conducted a survey to highlight these potential benefits. As discussed, respondents suggested enrolling decision makers in conducting the of industry 4.0 technologies such as Internet of Things (IoT) applications is a critical step for success, as it ensures effective implementation and minimizes risks.

“To **convince decision-makers** of the benefits of advanced technologies such as the Internet of Things (IoT) and BIM on the job site, it's essential to demonstrate how a person can easily check dimensions on their smart devices, allowing them to review CAD drawings easily and share them with others” (UK-INF-030).

“Managers should **prioritize the tangible benefits** of implementing Internet of Things (IoT) applications for long-term success. Actually, **long-term benefits** can encourage them to understand the impact of adaptability and investment in smart technology, making them more open to adopting innovative technologies” (UK-INF-001).

Developing a collective mentality regarding technology's usefulness in construction projects is crucial for increasing leadership and enhancing project success, as mentioned by one of the interviewees:

“I think, firstly, we need to establish a collective mindset recognizing the **necessity, importance, and relevance** of technology” (UK-INF-009).

Creating awareness among construction project decision-makers will be a crucial factor in implementing new solutions in the construction sector. A successful case study of industry 4.0 technology implementation could positively promote the implementation of new technologic approaches in construction projects.

“To increase confidence in adopting smart tools such as the Internet of Things (IoT) applications, it is essential to demonstrate more **regional success stories**. Local construction industries often overlook cases from other regions, such as massive construction projects in London or even the United States case studies, which may lead to a better understanding of the technology's effectiveness. To demonstrate its effectiveness, it is crucial to showcase more evidence from various smart construction projects throughout the UK or even other countries” (UK-INF-007).

“Absolutely, the **case study** is ideal, showcasing benefits and allowing people to see if similar events occur, demonstrating the potential for similar outcomes” (UK-INF-034).

To develop awareness among construction company decision-makers, it is crucial to create knowledge supporting and validating smart technology implementation. This could be achieved through various case studies of effective implementation of digital tools and techniques in the country of implementation, preferably in the same country. The case study should showcase the benefits and savings achieved through smart tools implementation, as well as the key challenges faced. The knowledge produced through case studies could be technical, objective, and easily shareable (Lia, 2018).

This section, in summary, highlights the importance of developing awareness among decision-makers in the UK construction sector, ensuring to achieve strong leadership. It suggests creating and sharing effective knowledge through case studies of successful smart technology implementation. This awareness leads to an impressive change in leadership, increasing awareness among top management to adopt innovation opportunities, and promoting investment in digital technologies. So, by adopting a culture of innovation and promoting the use of industry 4.0 technology such as Internet of Things (IoT) applications, the UK construction sector could implement a more innovative and successful workforce.

7.2.2 Staff training and development

According to Swanson (1999), training and development is the procedure of acquiring work-related information and skills in employees with the aim of enhancing performance progressively. Staff training and development were highlighted as a key influencing factor for implementing industry 4.0 technology such as Internet of Things (IoT) applications in the UK construction sector (30% of respondents). Interviewees suggested training for employees could be the key influencing factor to better understand and adapt to the new digital technology in the workplace:

“….to provide comprehensive training to employees with **limited knowledge** about smart technology, as many older and younger individuals struggle with these innovative technologies” (UK-INF-007).

Also, Interviewees recommend that training could be aimed to reduce employee resistance to change as follows:

"Implementing smart tools and technologies requires training to **overcome hesitant users**, as training is crucial for the successful implementation of industry 4.0 technology in the UK construction sector" (UK-INF-009).

The literature highlighted two distinctive dimensions of training and development to improve the efficiency of the employees in the construction industry. Principally, Smart tools and technologies, such as smartphones and tablets, could provide pertinent information and support agile on-job training for the workers and professionals in the construction industry. Smart boards, for example, could also be utilised to facilitate such training to the construction workers. Furthermore, construction organizations should encourage employee training to ensure the efficient implementation and adoption of these new technologies associated with the Internet of Things (IoT) applications (Kim, 2021; Panteli, 2021; Guo, 2021).

Construction employees could be trained on-the-job or off-the-job, according to Smith's (2002) presentation of two approaches. on-the-job and off-the-job training. On-the-job training offers new practices and involves courses on new regulations or processes. On the other hand, off-the-job training is a curriculum-oriented method and focuses on lectures and classrooms, and films to develop problem-solving skills. Furthermore, off-the-job training will focus on learning fundamental skills, while on-the-job training will emphasise activity to do an appropriate job.

Regardless of the staff training methods, this study requires to categorize of staff training options for construction staff members including information technology, marketing and sales, advanced technology in the construction industry, leadership and human resources, and business study Edum-Fotwe and McCaffer (2000). Over the last few years, Industry 4.0 technologies and IoT applications integrated into construction organizations. So, construction organizations should consult with consultants to obtain the latest development on the impact of smart tools and technologies such as the Internet of Things (IoT) in the construction industry including on human resources, sales, facility management, operation, monitoring, health and safety, and business and marketing (Kang, 2022). Employee desire to participate in training is another crucial factor in the training and development associated with personnel. So, motivation in the construction industry can be described as influencing their willingness to attend, exert effort, and apply the learned skills to the workplace (Felix Behling, 2015).

Tabassi and Bakar (2009) suggested three ways to motivate employees: worker participation, recognition as a team, and team belonging. To encourage employee participation, supervisors and managers could conduct a new training system that rewards good workers financially. Also, recognition to be involved in a team could be more effective than financial rewards, as noted by Nesan and Holt (1999). Ultimately, team belonging can be identified as more motivating when employees feel part of a group and have the opportunity to manage themselves. Overall, addressing these needs can help employees feel more engaged and motivated.

In terms of training and development, one of the interviewees suggested that universities as a significant source of training could play a crucial role in training new construction professionals to learn the latest software and programs:

"**University education** could be essential for introducing new technologies and their usage in the construction industry. Providing students with updates on the latest tools and technologiessuch as the Internet of Things (IoT) will enhance the organizational culture of the construction businesses and the entire industry. This knowledge could significantly impact the future of the construction industry" (UK-INF-001).

Finally, in order to encourage employees and workers in the construction sector to adopt training approaches, team-building activities, award recognition, and financial rewards are recommended. According to Tabassi and Bakar (2009), employees who feel their participation could be crucial for company success, leading to better performance and meetingorganizational needs.

7.2.3 Organisational culture

Organisational culture impacts professional goals, thoughts, and actions in the workplace, influencing task performance and resource allocation (Lok and Crawford, 2004). Interviewee (UK-INF-007) provided the following suggestion regarding culture as a difficulty, identifying as a key influencing factor:

“**Culture** could be a considerable **challenge** that links directly to success factors. employees require awareness and a change in culture. I am working in a construction company that justuses drawings and paper, it could be challenging to convince the employee and the management to focus on digital technology” (UK-INF-007).

So, based on the above comments, construction staff members and workers require cultural change, as long-term employees may struggle to adapt to digitalization in a company. One of the interviewees stated that a key influencing factor for a company to adopt the digital tools and technologies could be its mentality:

“I think the **organization's mentality** and lack of awareness about the drivers of implementing the digital tools and technology may address the issue” (UK-INF-032).

The interviewees reveal that the organization's mentality contributes to the lack of awareness about smart tools' implementation drivers and benefits. These results suggested that an appropriate organizational culture could foster creativity and innovation. So, the next phase isto identify the type of "appropriate" organizational culture for fostering innovation and creativity in the construction industry.

According to Goffe and Jones (1998), organizational culture could be categorized into four types; communal, mercenary, networked, and fragmented. However, Martin (1992) focused on four distinct perspectives including fragmentation, implementation, differentiation, and integration to examine the organizational culture. Liu et al. (2006) highlighted the dimensional and typology approaches to studying organisational culture. Wallach's typology approaches identify different forms of organizational cultures: creative, supportive, and bureaucratic. Other studies discovered numerous approaches to examine the different elements of organisational culture including socio-structural, social, psychological, and technical.

Kenny and Reedy (2006) defined an innovation culture as a mindset that creates and establishes values within a firm. This culture could improve the functioning of the firm, even if itconflicts with conventional behaviour. To adopt this culture, Kenny and Reedy suggested three attitudes: shared responsibility, willingness to take risks, and stimulation of creativity. These attitudes will aim for the construction industry to succeed in adopting an innovation culture.

Furthermore, Canalejo (1995) recommended adopting a creative organizational culture in the construction industry could be valued by focusing on client orientation, continuous improvement, overcoming challenges, objective commitment, and teamwork. Using these results from the literature, this study suggested addressing all dimensions of an innovative culture to foster a culture in the construction organisation.

This section discussed the importance of an innovative organizational culture in the successful implementation of industry 4.0 technology such as the Internet of Things (IoT) associated with smart tools and technologies. The literature provided suggestions for construction companies to adopt values that foster an innovative organizational culture.

7.2.4 Technology awareness

Technology awareness can be identified as the level of the users in order to understand the current state of technology, requiring the continuous collection of data and information associated with changes. One of the participants highlighted that the industry could more effectively embrace this technology if it adopts a collective mentality regarding the advantagesof smart technology.

“There are two types of professionals: those who are **knowledgeable about the latest technologies** and those who remain traditional. Also, it could be another group, the complicated group that requires demonstrating our capabilities and understanding their needs. They may take longer to adapt initially, but over time, it will become easier. By presenting our capabilities and understanding their reasons for changing, we can help them adapt and thrive in the new landscape” (UK-INF-038).

Adopting smart tools and technologies requires raising awareness about technology's benefits, particularly for young professionals in the construction industry as mentioned by another interviewee:

“We are required to Increase **young professionals' knowledge** about the advantages of using **smart applications** in the construction industry, encouraging them to increase the productivity of the company” (UK-INF-021).

Construction organizations aimed to establish a collective mentality, focusing on changing the industry's perspective, commencing with the creative younger generations, according to respondents:

“Embracing a collective mentality**, recognizing technology's necessity**, all are important” (UK-INF-007).

Also,

“**Benefits** and drivers of using **smart tools** may not be seen by everyone, but explanations of these benefits could change perspectives” (UK-INF-017).

Based on the statements from the interviewees, it could be identified that the education of the construction industry's professionals is crucial for understanding the benefits of technological tools, resulting in considering these responsibilities lying with the employer and the government. Employers are responsible for offering capacitation to employees, while the government could create policies and rules for conducting this plan. Furthermore, educational institutions by providing webinars, courses, and seminars could help to raise awareness of the benefits of adopting and usage of smart technology in the construction sector.

In summary, technology awareness could be recognised as the key influencing factor for implementing industry 4.0 technology such as Internet of Things (IoT) applications integrated with smart tools in the construction sector. Also, education is the core principle of technology awareness, and it is essential to provide an appropriate education level for both young and old construction professionals. Corporate culture plays a significant role in influencing technology awareness, as bureaucratic structures can hinder innovation.

An entrepreneurial mindset with increased responsibility for employees can lead to a better understanding of the benefits of technology implementation. An organization's culture is directly linked to employee awareness,and an increase in technology awareness requires a significant change in its organizational culture.

7.2.5 Cost

The cost and how to deal with the high cost of smart technology can be identified as another key influencing factor for the effective implementation of smart technologies in the construction industry. Furthermore, company size could influence the organization's ability to adopt and implement innovative tools and technologies. It is obvious that large construction businesses have larger budgets, making it easier to adopt and implement innovative and smart technologies. They may also have multi-city projects, encouraging and convincing them to adopt and implement innovative tools for their construction projects. It can be identified that the high cost of Implementation of Industry 4.0 technologies significantly impacts decision-making approaches in the construction industry, as noted by the respondent:

"I believe that implementing smart technology in a construction company requires **a cost-benefit analysis**, as it is essential but expensive**.** It is crucial to evaluate the benefits and drawbacks before deciding to proceed" (UK-INF-016).

The cost-benefit analysis of smart technology such as the Internet of Things (IoT) is crucial for decision-makers, as it helps determine the potential benefits of implementing digital tools and technologies and their potential earnings in the construction sector. Also, the positive cost-benefit analysis could encourage other construction companies to implement industry 4.0 technologies by demonstrating potential benefits. Actually, in large companies, the key encouragement for implementing industry 4.0 technologies such as the Internet of Things (IoT) applications associated with smart devices is to improve effective communication between management and the workforce, which typically leads to saving cost and time. Also, one of the Interviewee commented that investing to buy an industry 4.0 technology such as drones could help the construction sector for the long-term benefits to save cost and time:

"Our current project is to maintain a historical tower; this large construction company is usually interested in investment to buy digital and smart technologies to be implemented in the job site. For example, previously for monitoring the high height of the structure that sometimes was really challenging to access it, we need to spend additional **cost** to hire a specialist to makethe proper report of the current condition of the area. However, the management team decided to buy a **drone** that could be connected to the Internet of Things (IoT) applications to monitor the current condition of the structure properly and also make the considerable reportswith benefits including capturing high-quality images and films, accessibility on any time, fast transferring the data and information, reduce the risk of falling from height, live streaming, andso on. So, sometimes, investment in smart technology could lead to the **long term's benefits**" (UK-INF-015).

Also, another participant mentioned the high cost of implementation GPS to the mobile equipment of the job site as follows:

"It could be great but **costly** if we could be embedded **GPS** to all our mobile equipment such as lorries, shovels, scissor lifts, forklifts, and so on. Actually, project manager by using the Internet of Things (IoT) applications could monitor and control the specific amount of equipment that will require for the job on site as well as update the inventory in our construction company" (UK-INF-020).

In summary, the cost of implementing industry 4.0 technologies such as the Internet of Things (IoT) integrated with smart tools must be compared to the potential benefits of long-term cost savings obtained from the construction project. The cost will depend on the type of the project's nature, such as construction, infrastructure, commercial, and so on. It is crucial to examine the proper type of construction project to provide an appropriate cost-benefit analysisfor implementing smart technologies.

7.2.6 Size of the construction company

Company size could be significantly influenced by research samples, depending on the size of the company, various attitudes and perspectives are typically discovered. Lin and Mill (2001) highlighted the disparity in conducting occupational health and safety systems between large and small construction companies.

In the UK construction industry, in order to identify the size of the company, Small and Medium Entreprises (SMEs) are dominant, accounting for 99.5% of all construction businesses in 2016. Large companies account for 40% of private sector employment (Rhodes, 2015). Organisations are classified into micro, small, medium, and large based on employee numbers. Actually, 40% of the entire private sector employment is in large construction businesses. Depending on the number of employments, UK construction companies are divided into categories including micro, small, medium, and large oraganistion.

Company size is a direct link to project size, as small construction companies typically develop small construction projects. This affects the analysis and understanding of new processes and approaches in the construction industry. According to Al- Ghafly (1995), Large and medium-sized projects frequently experienced delays, which were deemed severe for smaller enterprises, making it crucial to consider this variable particularly when developing and establishing an effective framework for implementing smart technologies in the construction industry. Regarding this type of classification, respondents provided the following comments:

"I think the agility of work depends on the construction **company's size**, as some companies have limited technologies to perform the job digitally, making it difficult to adopt and implement smart technologies to improve productivity. However, as these companies will expand, such as larger ones, the agility of jobs will assist to enhance the standard of work, encouraging them to conduct smart technology such as the Internet of Things (IoT) applicationsin their current project, for example, in facility management or real-time monitoring" (UK-INF- 001).

"**Market size** will influence the decision to invest in certain tools. In fact, low benefit margins can prevent unnecessary investments. For example, If I need to manage multiple projects simultaneously, it can be beneficial to invest in some smart technologies that could help me to track and monitor equipment and everyone's activities. Tablets and Smartphones integrated with the internet connection can be convenient for monitoring projects, a drone may not be necessary for the nature of our current project. So, the market size plays a significant role in determining the decision to invest in smart tools" (UK-INF-005).

Also, one of the interviewees mentioned about the relationship between company size and availability of the training and development:

"My company can be classified as the large one, and because of **company size**, massive turnover, and financial transactions through the company, they can have a lot of opportunities to invest in **training and development** of their employees. For instance, recently, they provided us with an online application called Atlas, learning about the health and safety courses such as First Aid at work, Fire safety, wellbeing at work, etc. courses, we can use it at any time even outside working hours" (UK-INF-0014).

Also, construction industry professionals argued that because of the limited source of available budget, small companies are reluctant to invest in adopting and implementing smart technologies, while larger construction companies recognize the potential benefits of adopting smart technologies on multi projects including enhancing communication, improving the information and knowledge exchange, accurate real-time monitoring, and reducing the energy consumption.

Briefly, company size is a crucial factor in implementing industry 4.0 technology such as the Internet of Things (IoT) and smart devices. Factors such as employee numbers, the size of the project, and the nature of the projects could be determined the requirements for implementing smart technology in any construction industry. Primarily, because of their funding and budget, larger organisations obviously have the advantage over smaller ones in implementing smart tools and technologies.

7.2.7 Usability

Usability refers to the effectiveness of a system's interaction and user experience, incorporating the user's emotions and decision-making abilities (Love et al., 2015). Smart technology applications should be user-friendly, encouraging further implementation and fostering positive user interactions. Respondents emphasized usability as one of the crucial factors for implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector.

"The key to a successful implementation of smart technology is making it as **user-friendly** as possible" (UK-INF-033).

Also,

"…. ensuring **ease of use**, high-quality internet connectivity, and existing infrastructure (software and hardware) for implementing smart tools and technologies" (UK-INF-007).

So, smart technology usability in construction projects depends on factors like project conditions and necessary changes. Adopting and implementing smart tools and technologies should examine these factors and conduct technology-based solutions before implementation.

Interoperability is another key factor for considering the term usability in implementing smart tools in the construction industry, as it allows the equipment to exchange information. A lack of interoperability could result in significant time and resource expenditures, making greater interoperability essential for organizations to move efficiently between projects (Forbes, 2017). Integrating new tools and technologies in smart devices and the Internet of Things (IoT) relies on ease of integration with current tools and technologies. By applying sensor connectivity, existing equipment could be transformed into smart devices, enhancing interoperability and facilitating the implementation of innovative tools and technology, as one of the interviewees highlighted:

"Implementing the **GPS could be so easy** due to the installation of a SIM card and additional hardware. Then, capturing information and employing it. However, in terms of usability, the more difficult an implementation, the more likely it is to fail, especially in the construction industry" (UK-INF-007).

According to the respondent, implementing new tools and technologies may be hampered by the challenges associated with integrating new technology with current equipment. There are many various types of construction projects, and each one employs a particular set of equipment to complete its task. The Internet of Things (IoT) enables objects to be connected to multiple networks of tools, gathering project information and data. To transition from traditional construction methods to a new approach incorporating IoT, interoperability between these new and existing technologies is crucial.

In a nutshell, positive usability involves user-friendly devices, requiring awareness of site conditions like project location and network infrastructure. Construction organizations should evaluate the requirements of smart tools usage based on existing equipment, as integration and interoperability with existing tools lead to more scalable deployments. This ensures a seamless user experience and ensures a smooth transition to new devices. Smart tools will be required to exchange information and communicate through networks for interoperable functionality. However, integration necessitates greater connectivity between devices so that they behave as one unit.

7.3 Summary

This chapter discusses the key influencing factors (KIFs) for implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector, derived from 38 semi-structured interviews with construction professionals in the UK. This chapter highlights the significant key influencing factors (KIFs) for implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector including technology awareness, size of the company, cost, leadership and management actions, and usability of the devices, resulted in identifying by 36% of interviewees that the leadership and management actions as the most relevant KIF.

Adopting a collective mentality considering smart technology's benefits is crucial for increasing leadership in the construction sector. Also, convincing decision-makers about the benefits of implementing new tools and technologies is another key influencing factor for the successful adoption and implementation of these smart technologies in the construction business. Furthermore, enrolling decision-makers in new devices can be a good approach to promoting the adoption of smart tools and technologies such as the Internet of Things (IoT).

Technology awareness is the other significant factor for users' perception of smart technology, emphasizing the need for education in the construction industry to better understand available smart tools and technologies. Construction industry professionals emphasized the importance of company size in technology investment. Small construction businesses may lack resources, while larger companies by getting more opportunities to work on multiple projects could allow the manager to better control projects and also improve communication between stakeholders and employees as a result of adopting and implementing industry 4.0 technologies.

This chapter investigates the key influencing factors (KIFs) for implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector. The framework development for adopting and implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector will be discussed in the next chapter.

Chapter 8. Developing a framework for IoT implementation

8.1 Introduction

This chapter provides a developing framework for the implementation of the Internet of Things (IoT) in the UK construction sector, considering previous investigation findings. It presents a better understanding of drivers and barriers to implementing the Internet of Things (IoT) applications integrated with smart devices and offers an interpretative strategy for the social reality of the construction sector.

The developed framework seeks to evaluate productivity improvements such as labor efficiency and economic growth by adopting and implementing the Internet of Things (IoT) in the UK construction sector. In fact, this chapter addresses the fifth objective of the research study to develop a framework for the implementation of the Internet of Things (IoT) application for stakeholders to understand the impact of IoT adoption in the UK construction sector.

This chapter presents the following sections including the rationale, vision, target audience, functionalities, validation, and summary of the proposed framework. It is structured in sections 8.2,8.3,8.4,8.5, 8.6, 8.7, and 8.8. respectively.

8.2 Rationale for developing a framework in the construction sector

According to Lombardi and Barber (2011), there is a view that long-term performance difficulties have remained to hinder the UK construction industry to be one of the most productive industries. Liu (2018) claimed that several clients are unsatisfied with the overall performance of the construction industry, and disappointed with the level of the construction industry's productivity. Furthermore, it is acknowledged that the construction industry commonly has huge concerns about the delivery of projects on time and under budget (Love & Skitmore, 2012).

A series of significant reports on the construction industry, including the Latham Report Latham (1994) and the Egan Report Egan (2002), have been issued to explain some of the underlying issues in the construction industry such as discontinuity, adversarial attitudes, labour shortage, and fragmentation. To address these issues, technology managerial innovations will be conducted to help the construction industry to improve productivity and profitability (Kaplinski, 2018). Also, Crotty (2013, p. 25-28) claimed that improving communication could be crucial for addressing construction industry issues. Furthermore, the challenges are unique and need particular efforts to tackle the challenges by implementing of IT solutions with the appropriate investment of the value chain at any stage of the construction process (Oesterreich, 2021).

So, smart technologies integrated with the Internet of Things (IoT) are efficient tools for improving communication and information exchange between construction stakeholders, connecting devices and enabling automated machines in any stage of the construction work environment. This network enhances communication, ultimately improving stakeholder satisfaction and overall efficiency. So, with the current trend of digital transformation and increased use of data in the construction industry, this research attempts to develop a framework for the implementation of the Internet of Things (IoT) application that will be useful for stakeholders to understand and impact of IoT adoption in the UK construction sector.

The UK government is attempting to implement smart construction technologies such as the Internet of Things (IoT) as a significant initiative, aiming to reduce the industry's initial cost of construction and assets by 33%. HM Government (2015) believes that facilitating data interaction between the construction stages of supply chain assets will assist to accomplish these benefits. This could be achieved through the integration of the constructionsector with control systems, focusing on the Internet of Things (IoT) paradigm for new construction processes.

In the UK construction organisations, 90% of interviewees stated the need for a strategic and efficient framework for implementing Industry 4.0 technology such as the Internet of Things (IoT) integrated with the smart devices in their construction processes. The analysis of data from 38 interviewees, combined with the mentioned crucial issues, supports the need for an effective framework for implementing the Internet of Things (IoT) application in the construction sector. Also, the findings from the qualitative data collection indicate the validityof developing such a framework for implementing the Internet of Things (IoT) application in theconstruction sector.

8.3 Vision

Implementing the Internet of Things (IoT) applications could boost economic growth and labor efficiency in the UK construction sector.

8.4 Aim

- Encourage UK construction businesses to adopt Internet of Things (IoT) applications.

For construction businesses seeking certainty on the Internet of Things (IoT) applications implementation could employ this framework for their construction projects.

- Develop a strategic framework for conducting the Internet of Things (IoT) applications.

For construction businesses that have already agreed to implement Internet of Things (IoT) applications.

8.5 The framework is useful for?

A strategic framework will be presented for the construction industry stakeholders to implement Internet of Things (IoT) applications in the UK construction projects, aiming to understand benefits and barriers, enabling organizations to effectively implement Internet ofThings (IoT) applications in the sector.

The proposed framework follows Rogers and Shoemaker's (1983) innovation-decision paradigm, offering a persuasion-decision structure to encourage effective and successful smarttechnology implementation in the construction industry. In addition, it presents an implementation structure for adopting and conducting smart technologies from initial planningto the construction phase. Also, this framework is designed for construction businesses developing projects and benefiting from technological advancements.

The proposed framework will be designed for construction organizations exposed to industry 4.0 technologies such as the Internet of Things (IoT) paradigms, requiring an understanding of related tools and technologies and their functions.

8.6 Proposed framework for implementing IoT in the constructions sector

The proposed framework outlines a strategic approach for organizations to implement the Internet of Things (IoT) paradigms into daily activities in the UK construction sector. It includesa persuasion and implementation framework, following Rogers and Shoemaker's (1983) innovation decision strategy, which involves five stages as seen in Figure 13:

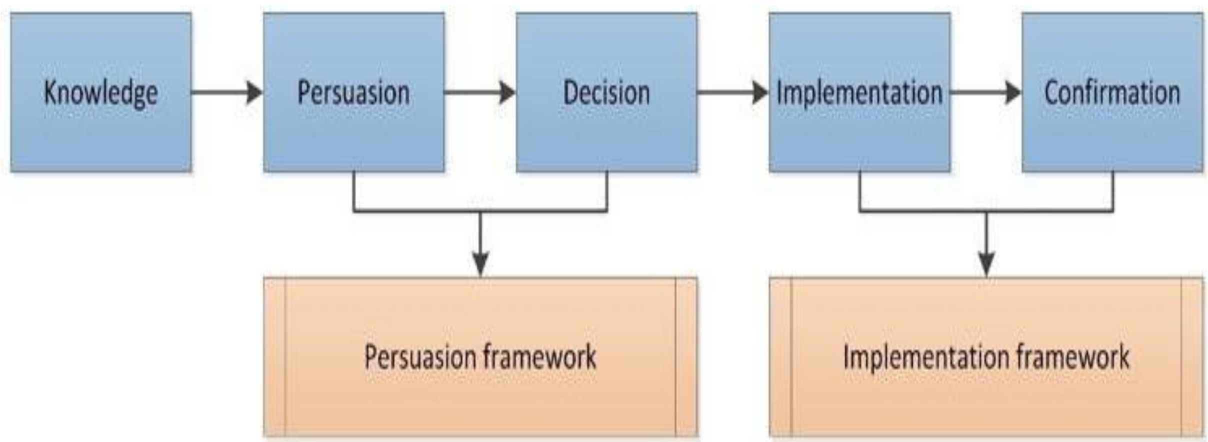


Figure 13 Rogers' Innovation-decision process and its relationship with the developed framework Rogers and Shoemaker (1983)

Rogers and Shoemaker (1983) identified effective innovation decision procedures as starting with individuals becoming aware of an innovation's benefits, such as smart devices. The persuasion stage occurs when individuals develop a positive or negative perception of innovation.

Next, the proposed framework outlines critical actions to encourage technological innovation, influencing decision-makers in construction organizations to understand the impactof smart technology adoption. The decision stage involves individuals or organizations choosingto implement or ignore innovation. Figure 8 presents actions to encourage smart tool implementation, promoting a positive perspective toward innovative technologies.

The implementation stage involves organizations implementing innovations, while the confirmation phase seeks reinforcement of already adopted innovations. The proposed framework could assist construction companies to adopt this framework, revising and improving their Internet of Things (IoT) systems, particularly for those already implementing smart devices.

Firstly, the proposed framework presents a persuasion framework for incentivizing technological creativity and innovation in the construction sector, considering suggested actions in both organizational and external contexts. Then, it also presents an implementation framework, illustrating an iterative approach between an Internet of Things (IoT) system provider and construction businesses.

The framework seeks to assist construction organizationsin the construction sector in adopting industry 4.0 technologies such as the Internet of Things (IoT), focusing on Roger’s innovation's decision confirmation and implementation phases.

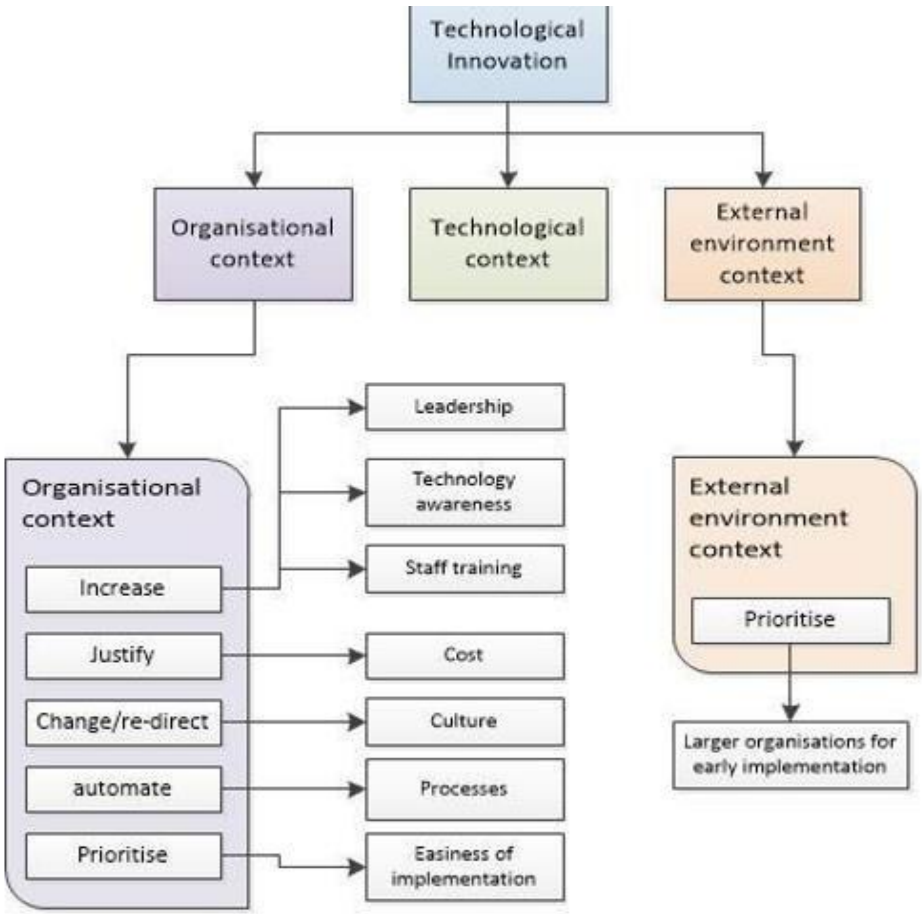
The persuasion framework aims to attract technological innovation in construction businesses by promoting the adoption of smart tools in their approaches. This framework could use as a strategic guide for implementing smart tools and technologies, attracting more construction companies to adopt these technologies.

8.6.1 Persuasion framework

The framework outlines suggested actions to encourage technological innovation in Construction organisations, promoting smart tool implementation, as shown in Figure 14. The data collected reveals actions and recommendations to contribute to the construction industry innovation.

In order to fully understand the framework, construction organizations must understand the process of adopting and implementing technological innovations, which is influenced by external, technological, and organizational contexts (Baker , 2012). This framework enhances technological innovation in construction organizations, considering external and organizational contexts.

Figure 14suggested actions to encourage technological innovation in Construction organisations



According to (Baker 2012), the organisational context includes the firm's features and resources, such as employee structures, communication processes, and resource availability. The technological context covers relevant technologies used and available in the marketplace. The external environment context provides the link between the industry structure and the regulatory environment. Chapter 7 outlines key influencing factors for implementing industry 4.0 technologies such as the Internet of Things (IoT) paradigms in the construction sector. Data analysis and literaturecorroborate findings within Tornatzky,(1990) organisation's framework. This research investigation collected data on an organizational level, focusing on the organizational context.Also, the analysis revealed recommendations for evaluating the external context. No recommendations were made for the technological context, however, a description was provided based on examining the existing literature.

8.6.1.1 Organisational context

Construction companies can adopt a variety of activities within the organisational context as shown in Figure 8.2. Construction companies should increase staff training and development, enhance technology awareness, and improve leadership, justifying the cost of Internet of Things (IoT) applications in construction projects. They should also create a culture shift towards technology implementation, prioritize Internet of Things (IoT) applications, and automate construction activities that associate with existing technology. Also, encouraging decision-makers to embed smart tools and technologies in construction operational processes is crucial for enhancing leadership and ensuring successful implementation.

Also, the crucial step in implementing innovative technology in a construction firm is informing decision-makers about the possible advantages of smart devices. Following the implementation of smart technology, a successful case study could positively promote advanced technology among decision-makers. Increased Internet of Things (IoT) awareness will boost workforce and decision-makers' perception, requiring constant information collection and staff training to adopt and implement the new technology. This leads to a more efficient implementation of smart tools and a higher level of technology awareness among decision-makers.

The cost of implementation is an important factor for small and medium enterprises (SMEs), as they may be less likely to adopt new technologies without a return on investment. Advanced technology such as Daqri Helmet, which cost £15,000 in 2023, provides a high cost for these companies (small and medium size). Health and safety are essential considerations for robots, which could replace human labor in hazardous environments, such as bridge inspections, due to existing dangers. While it may be expensive, it is essential for scouring and time savings in construction projects. Time savings are also crucial for project planning, as some projects must be completed within a strict timeframe.

Organizational culture is influenced by socio-economic and geographic factors, with companies adopting new paradigms or reluctance to implement them. To conduct new technology, organizations must remodel processes and evaluate the culture of individuals. Re-education involves changing staff perspectives to be more receptive to new technology.

Another significant stage towards promoting the Internet of Things (IoT) applications and smart device adoption in construction projects is automating processes before implementing a new system. For example, a company using smartphones and tablets may want to adopt and implement smart boards to adapt to meetings among stakeholders. However, optimizing processes, changing project management systems, and utilizing existing smartphones and tablets could minimise the frequency of meetings and potentially eliminate the need for a smart board. So, smart devices constantly evolve, and new devices could provide automation of existing ones.

8.6.1.2 External environment context

In chapter 9 of this research, data analysis suggested medium and large companies should prioritize implementing smart tools and technologies in the construction industry due to their extensive operations and ability to become pioneers, rather than small companies with few adopters of the new technology. Rogers and Shoemaker (1983) generalize early and late innovators' knowledge, highlighting the importance of understanding their contributions. It could be resulted that, earlier knowers of an innovation have higher education, social status, exposure to mass media, and interpersonal communication than later knowers. They also have more change agent contact, social participation, and cosmopolite tendencies. These factors contribute to their influence on the innovation's success and influence on later knowers.

Large and medium construction businesses have more advantages over small firms, according to Rogers and Shoemaker's generalisations. However, Geoffrey Moore's "chasm" is crucial in the external environment context. Moore's technology adoption life cycle begins with innovators (2.5%), early adopters (13.5%), next, the early majority (34%), then, late majority (34%), and finally, laggards with (16%). When the vast majority of clients agree that the productis convenient, the "chasm" is over, as shown in Figure 15 by *Moore (1991)*..

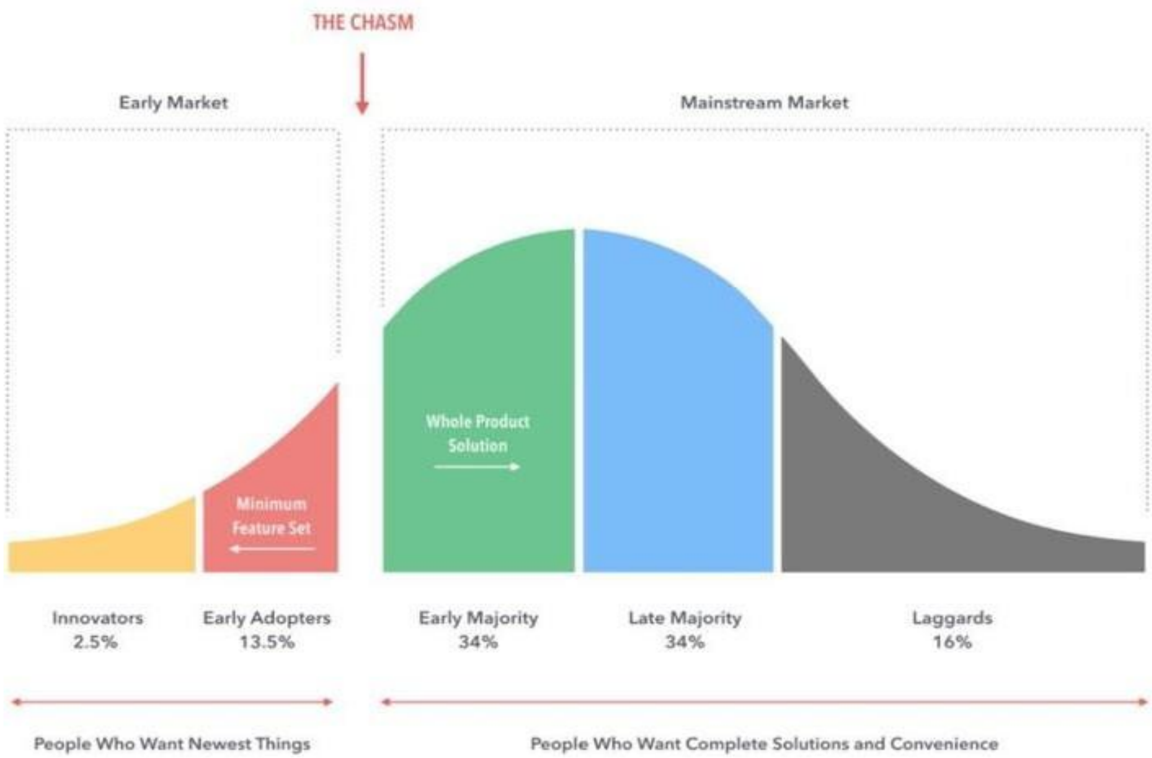


Figure 15 Diagram of the "chasm".

In the beginning, theory advises construction companies to offer innovative technological products. Then, the theory suggested construction organizations embedding smart tools and technologies in daily operations could view themselves as an effective innovator, crossing the "chasm" to offer a new product.

8.6.1.3 Technological context

The technological context encompasses relevant tools and technologies for construction organizations, including those already implemented and available for adoption in the marketplace. Following technological innovations, construction organization innovations can be categorized into incremental, synthetic, and discontinuous types, as explained by Baker (2012). These technological innovations can be explained as follows:

Innovations can be incremental, synthetic, or discontinuous. Incremental innovations introduce new features of existing technologies, while synthetic innovations combine ideas and tools in an innovative manner. Discontinuous innovations involve transitions from current tools and technology, such as cloud computing in early 2000s.

8.6.2 Implementation framework

The framework outlines an action plan for implementing the Internet of Things (IoT) applications in construction businesses. It involves a construction company, the Internet of Things (IoT) applications provider, and the Internet of Things (IoT) system. The company specifications are crucial, and a feasibility analysis is conducted based on data collection and literature. The framework's workflow in this study is presented in section 8.6.2.4, and it discusses an iterative process for the IoT system provider and construction firm to exchange information and determine the optimal Internet of Things (IoT) system for implementation, as seen in Figure 16.

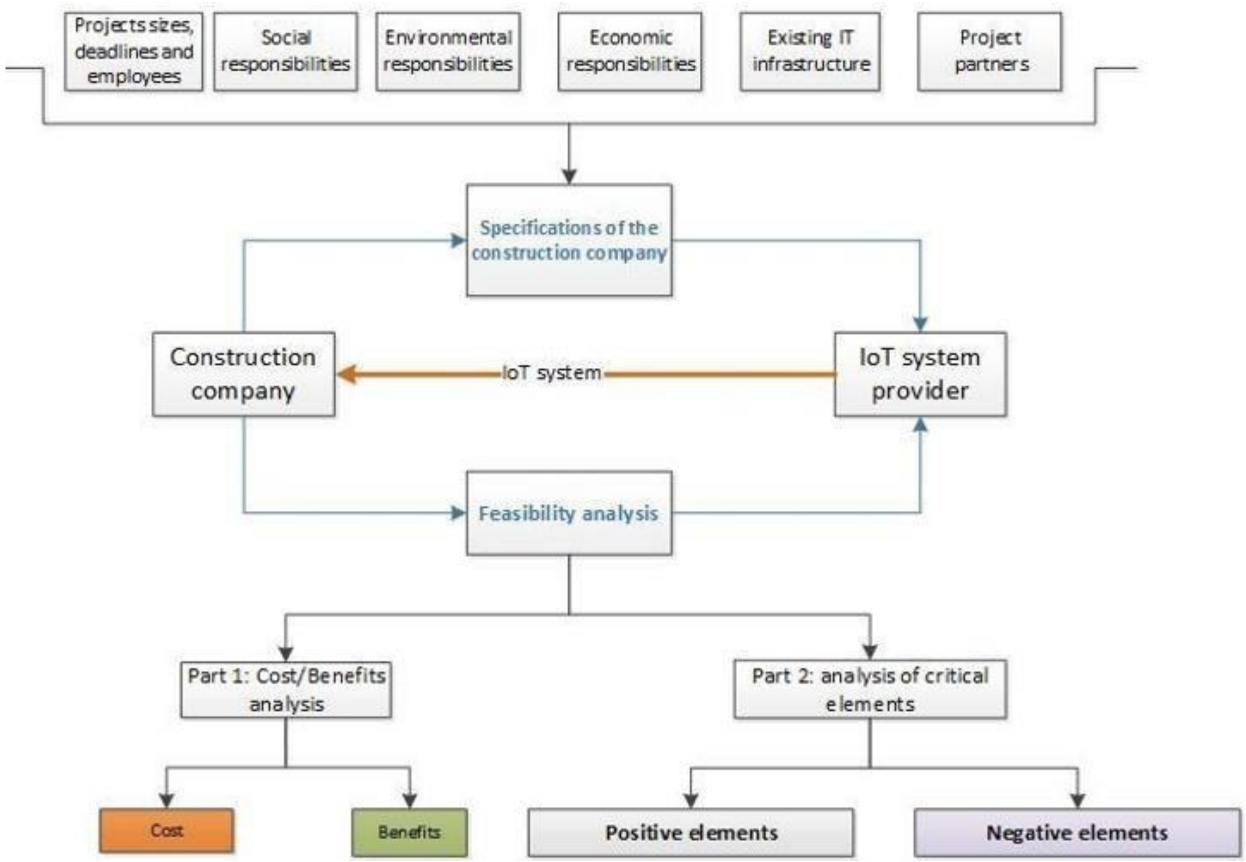


Figure 16 Workflow of Implementation framework

The construction sector is project-based, with the Internet of Things (IoT) systems aiming to increase communication and mobility between projects. This could assist in reducing fragmentation among stakeholders and improve communication between projects (Box, 2014). The developed framework focuses on implementing the industry 4.0 technology such as the

Internet of Things (IoT) in the construction sector, considering Chapters 6, 7, and 8, analyzing drivers and challenges, and understanding key influencing factors. A literature review and data review aided in its development.

The organization of the construction sector and its stakeholders could benefit from the implementation of a framework that generates valuable information for adopting Internet of Things (IoT) systems in their processes. Figure 17 displays the successful outcomes of each stage of the framework implementation. The outcomes obtained after each stage of the framework remain relevant, requiring organizations to revisit and track their development as needed. The first stage output could be useful for achieving various goals beyond the framework.

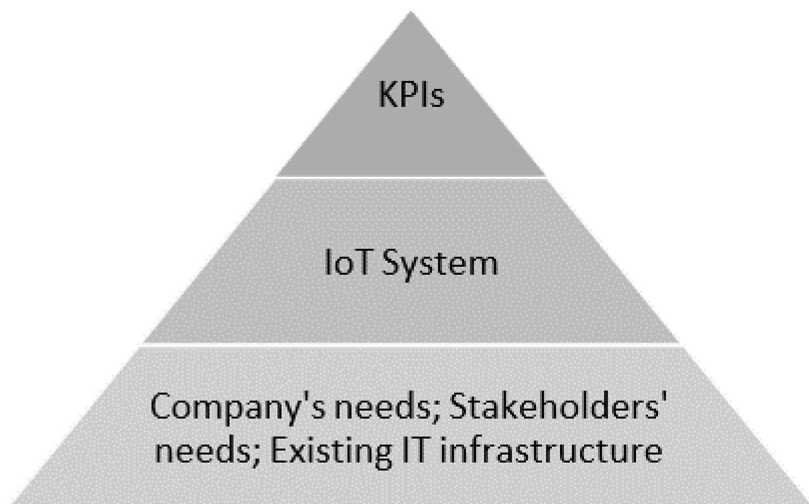


Figure 17 Pyramid of output produced by the proposed framework

8.6.2.1 Actors

The construction company could offer services to various clients in the construction industry, including painting and plumbing, architecture, cleanrooms company, facades, project management company, etc. Also, IoT service provider offers consultancy, advising on the best Internet of Things (IoT) system implementation for Information Technology (IT). And finally, IoT systems are a collection of computing technologies, including cameras, smartphones, Wi-Fi networks, laptops, servers, tablets, and smartboards. They complement traditional IT systems, focus on computing machines, and offer potential benefits for companies.

8.6.2.2 Specifications of the construction company

Construction company specifications are essential for achieving an Internet of Things (IoT) system, encompassing environmental responsibilities, economic, IT infrastructure, and social, as shown in Figure 18.

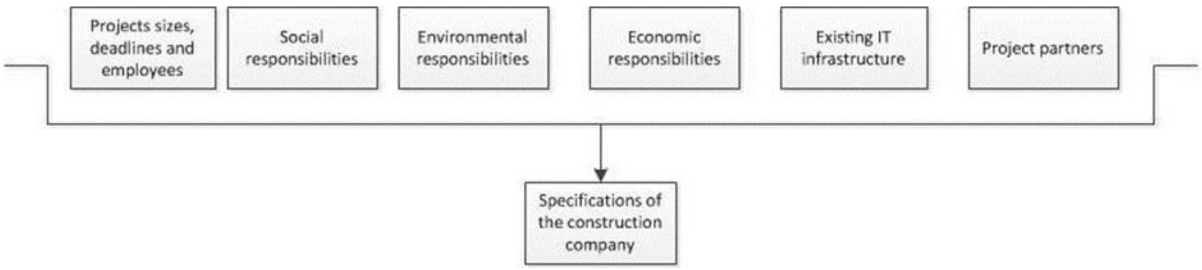


Figure 18 Specifications of the construction company

Project specifications should include deadlines, project aim, size, communication requirements, and other relevant information for technology consultants. Also, they could present the project's environmental responsibility, economic, and social. The company's existing equipmentand integration with new technology are important data for the framework. Performance analysis of these technologies will enhance productivity and workplace efficiency, ensuring the company's success in integrating technology and smart devices effectively.

Project partners can be described as all stakeholders involved in a project, as defined by Freeman (2010), who could affect or be affected by the organization's goals and objectives. Also, Eden and Ackermann (1998) defined stakeholders as individuals or small teams with the power to influence, negotiate, and alter an organization's strategic future. As we now identify stakeholders and map their impact on the construction project, we could understand their requirements and how the construction organization connects with them. Finally, we are required to list technological resources for input in the strategic framework.

8.6.2.3 Feasibility analysis

The feasibility analysis involves two processes to determine the most appropriate implementation for construction organisations. The layout of this phase and its procedures are shown in Figure 19. The first stage involves a cost and benefit analysis, considering direct and indirect costs, and benefits. The second stage analyzes critical elements, such as health and safety, Use of unmanned devices (robots, drones, etc.), and the project location's safety concerns. These elements can be of great relevance to decision-makers and help determine the most suitable implementation for construction companies.

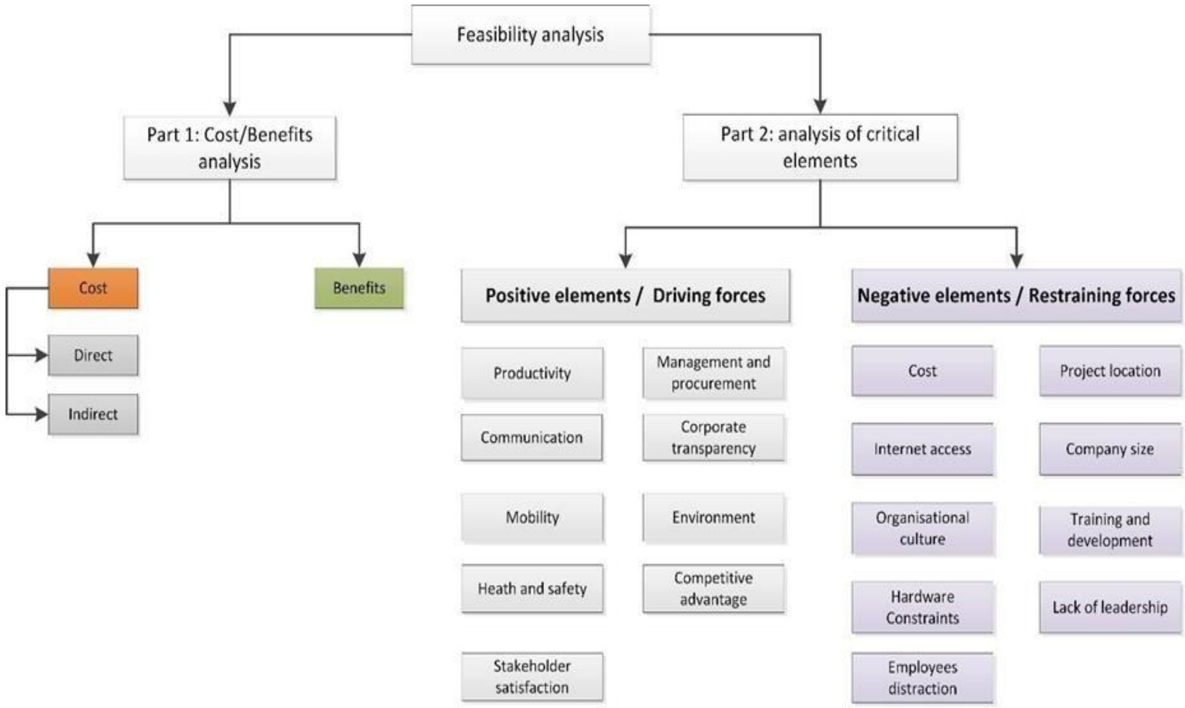


Figure 19 Feasibility analysis diagram

8.6.2.3.1 Cost and benefit analysis

Understanding and examination of Information Technology (IT) involves assessing the impact ofa proposed system on projects. IoT systems are sub-domains of IT, and literature on appraisal could guide this framework. Justifying investments in IoT projects is a challenging step in the implementation procedures, as demonstrated by Love and Irani (2001). This is particularly true for managers and supervisors in construction organisations.

Cost and benefit analysis is significant in the construction industry's evaluation of IoT projects. However, the industry often overlooks the indirect costs and benefits of IT implementation, often using traditional appraisal techniques. Also, quantifying IT implementation costs is complex and time-consuming, making it a challenge in evaluating IoT systems.

Return on Investment (ROI) is another crucial variable in evaluating the feasibility of technological innovations. Implementing a technological innovation in a stakeholder may result in higher ROI for another, similar to BIM. Although ROI is challenging to quantify due to intangible and tangible factors, it is essential in evaluating the feasibility of smart devices. The framework's process part presents technologies and recommendations for quantitatively evaluating IoT systems. It considers all possible variables and allows construction firms tochoose the most beneficial implementation level.

Cost and benefits are also important in decision-making, and a cost-benefit analysis helps companies determine the adoption level of smart devices. This helps conduct clear boundaries for maximum implementation, ensuring a company's financial viability in adopting these technologies. The framework suggests using Love and Irani's (2001) investment appraisal techniques to evaluate the cost and benefits of IoT systems, considering factors like critical success factors, competitive advantage, technical importance, and research and development. Furthermore, construction companies should recognise indirect and direct costs in IoT systems, including human and organizational costs as indirect and direct costs respectively. Figure 20 shows these costs, based on Love and Irani's (2004) research.

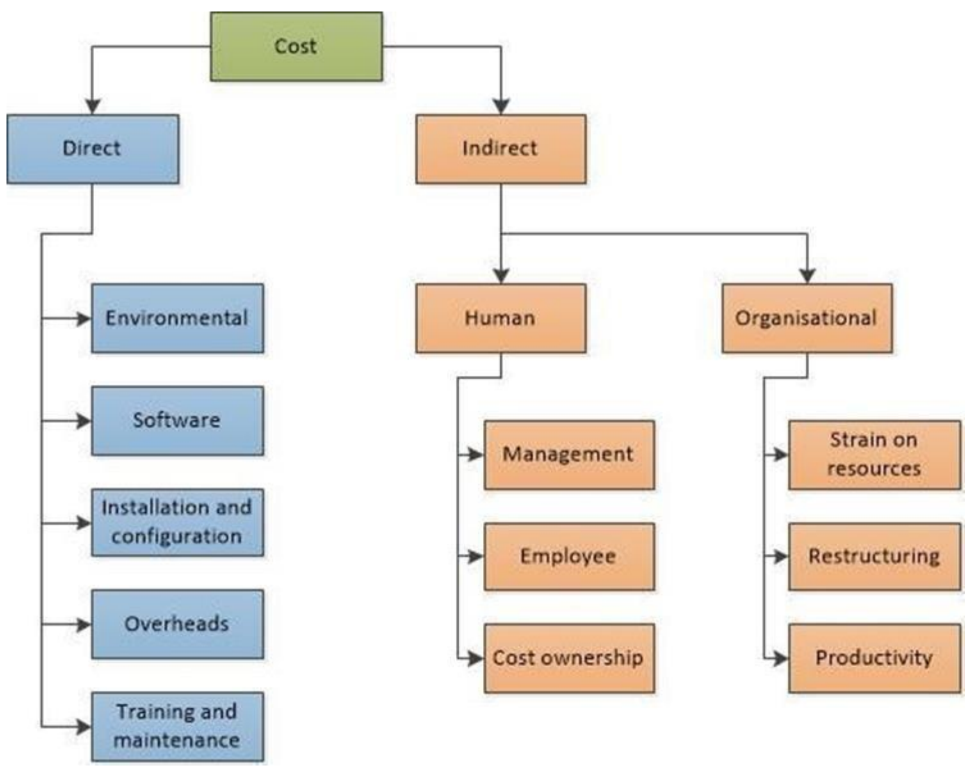


Figure 20 Scheme of types of cost in construction projects

Construction projects often have indirect costs, which can be attributed to cost ownership, management, and employees. Management costs can come from resources, time, and effort, while employees' costs can come from motivation, training, and time. The cost of ownership can be included as system support to find and address the issues. Also, Management time can be identified as an important indirect cost to construction companies. New technology implementation requires management time for system integration, potentially requiring revising IT strategies and involving additional planning in workplace systems. On the other hand, construction projects' indirect costs include organizational restructuring and productivitylosses.

Quantifying benefits of IoT investments is challenging due to the intangible factors and significant benefits, as cited by Powell (1992) and Andresen et al. (2002). Also, construction companies should identify the various benefits of IT innovation, as defined by Andresen et al. (2002). These benefits are categorized into performance benefits, effectiveness benefits, and efficiency benefits. Efficiency benefits can be described as quantifiable variables and could define by money, while performance benefits could be identified as qualitative variables and measured by the impact of implementation on long-term performance. Finally, improved operations provide a benchmark for effectiveness benefits. Table 11 will present benefits for construction organizations to use in feasibility analysis, focusing on efficiency, performance, and effectiveness benefits.

Table 11: Suggested benefits for apprising a projects' feasibility

Efficiency benefits	**Performance benefits**	**Effectiveness benefits**
Reduced planning times	Strategic competitive advantage	Faster response to supplier
Ability to handle moreenquiries	Improved idea sharing among Projects teams	Improved quality of output
Reduced communication costs	Improved project relationships with strategic partners	Improved control of cash Enhanced ability to exchange data
Reduced paperwork	Improved full life-cycle information management	
Reduced procurement costs	more effective assembly of project teams	
Reduced procurement times	Improved human relations	
Reduced construction times	Increased responsiveness of senior management to business problems	

The key challenge in quantifying the costs and benefits of IoT systems could be the limited data on efficiency, performance, and indirect costs. Following the result of this section, a feasibility analysis is conducted to evaluate various cost variables such as direct and indirect costs, also, benefits variables including efficiency benefits, performance benefits, and effectiveness benefits.

8.6.2.3.2 Critical elements analysis

Chapters four and five of this study provided the benefits and challenges of implementing the Internet of Things (IoT) integrated with smart tools in the UK construction sector. As shown in Figure 21 Positive driving forces and negative restraining forces are displayed. Health and safety, as an important example, are more important for construction organizations due to their nature of operation.

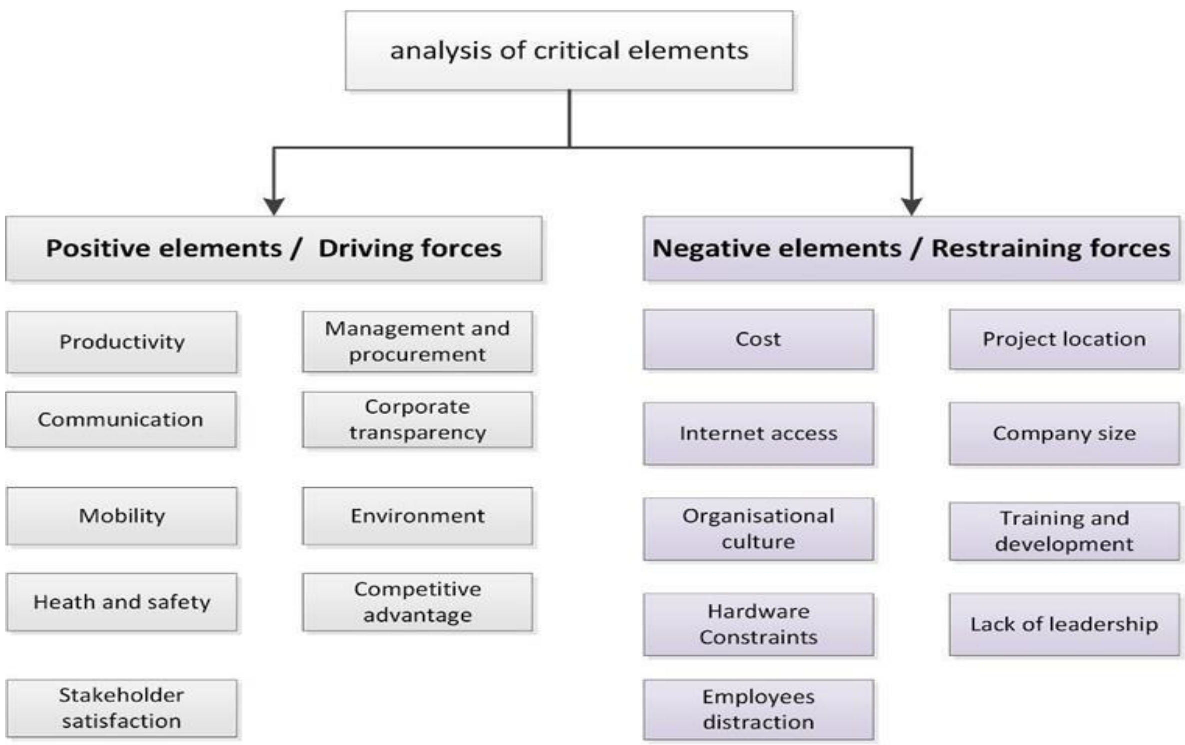


Figure 21 Driving vs Restraining forces for implementing IoT in the construction Industry

Positive Elements: In terms of critical elements based on the data collection from interviewees, drivers as a positive elements are including as environmental protection, productivity, corporate transparency, mobility, management, health and safety, communication, stakeholder satisfaction, procurement, and competitive advantage. The interviewees' highlighted productivity as their primary incentive for adopting smart devices in construction projects, with majority of the respondents indicating productivity as an advantage. Interviewees emphasized the importance of mobility in accessing data and visualizing project information, with using smart tools and technologies being the second most significant benefit.

The literature, as well as the interviews, claimed that smart tools and technology such as the Internet of Things (IoT) could completely revolutionise how construction employees share data and information. As a result, communication is a crucial factor that affects stakeholder satisfaction, corporate transparency, and mobility.

Following the next driver, smart tools and technology such as the Internet of Things (IoT) contribute to environmental protection in the UK construction sector by reducing paperwork in construction projects and identifying with numerous companies implementing paperless construction projects. The least discussed benefits of implementing smart tools and techniques such as the Internet of Things (IoT) in the construction sector include stakeholder satisfaction, competitive advantage, corporate transparency, and health and safety. However, these drivers presented valuable and reliable insights into the endless possibilities and motivations behind conducting and adopting digital tools and technologies.

In certain situations, organizations may identify critical elements that drive the implementation of smart tools and technology. For instance, a construction company may need to deliver a commercial project within a particular timescale, using smart technology could assist them to proceed with the job quicker. Also, on other construction projects, mobile cloud computing can help to achieve budget requirements. Furthermore, managers may require weekly video calls based on the job location to communicate and exchange information with the other stakeholders. And a strong health and safety culture may encourage the use of unmanned devices such as drones for safety reasons. By implementing these technologies, organizations can achieve their goals and reduce costs while ensuring the success of their projects.

Negative Elements: On the other hand, barriers as negative critical elements are categorized into economic challenges, cultural issues, and technological barriers. Economic challenges present the high cost of smart tools, investment issues, and cost of training, hiring skilled employees, and company size. Construction industry professionals emphasized the importance of company size in technology investment. Small construction businesses may lack resources, while larger companies by getting more opportunities to work on multiple projects could allow the manager to better control projects and also improve communication between stakeholders and employees as a result of adopting and implementing industry 4.0 technologies.

It is obvious that large construction businesses have larger budgets, making it easier to adopt and implement innovative and smart technologies.

They may also have multi-city projects, encouraging and convincing them to adopt and implement innovative tools for their construction projects. It can be identified that the high cost of Implementation of Industry 4.0 technologies significantly impacts decision- making approaches in the construction industry.

It would be recommended by the interviewees that the Government could assist in this matter by funding the construction companies to invest in digital technologies or even providing untaxable scheme to buy digital tools and equipment, trying to encourage the stakeholders particularly for the small and medium firms to purchase these smart technologies.

Also, cultural challenges address organizational culture in the construction industry. Kenny and Reedy (2006) defined an innovation culture as a mindset that creates and establishes values within a firm. This culture could improve the functioning of the firm, even if it conflicts with conventional behaviour. To adopt this culture, Kenny and Reedy suggested three attitudes: shared responsibility, willingness to take risks, and stimulation of creativity. These attitudes will aim for the construction industry to succeed in adopting an innovation culture.

Furthermore, Canalejo (1995) recommended adopting a creative organizational culture in the construction industry could be valued by focusing on client orientation, continuous improvement, overcoming challenges, objective commitment, and teamwork. Using these results from the literature, this study suggested addressing all dimensions of an innovative culture to foster a culture in the construction organisation.

Also, in terms of technological challenges, the implementation of smart tools in the construction sector is hampered by hardware, software, and technology limitations. According to Xu (2018) governance and leadership will influence decision-making in ventures, and construction industry organizations by adopting leadership toward innovation activities will receive effective management sponsorship for implementing new technological approaches. Interviewees suggested training for employees could be the key influencing factor to better understand and adapt to the new digital technology in the workplace.

Following the analysis of the interviewees, majority of interviewees presented cultural challenges as the top challenges in the UK construction sector. Organizational culture could impact professional goals, and conscious and subconscious thinking, making it a significant challenge for the sector. Also, some of the of interviewees identified that to implement innovative technology such as the Internet of Things (IoT), technological challenges should be addressed in the construction sector including GPS accuracy limitation, poor usability of the digital technology, battery life, poor performance of the smart devices, and internet accessibility.

The framework is considered the driver and barrier force of implementing an the Internet of Things (IoT) system in construction projects. Construction companies could analyze these forces and select critical elements based on staffand socio-economic situations.

8.6.2.4 Framework workflow

The implementation framework outlines the workflow for implementing an adequate Internet of Things (IoT) system in construction organizations, involving actors, company details and specifications, and the important one that could be feasibility analysis. The construction company must establish a feasibility analysis and specifications for the Internet of Things (IoT) service provider, which can present an Internet of Things (IoT) system for the company to adopt and implement.

The iterative process involves Internet of Things (IoT) service providers participating in a construction company's feasibility analysis, and negotiating an appropriate proposal. A new Internet of Things (IoT) system could be proposed, which is then analyzed by the construction company. The construction organisations present their feasibility analysis to the Internet of Things (IoT) service provider, and the process ends when the company chooses an Internet of Things (IoT) system.

8.6.2.5 Definition of KPIs

The construction organization can create a list of suggested Internet of Things (IoT) systems or smart tools based on previous stages' results, considering both qualitative and quantitative feasibility, and critical elements. This section provides guidance on establishing a Performance Measurement System (PMS) to monitor Key Performance Indicators (KPIs) in construction projects utilising this framework. According to Neely et al., (1995), construction organizations could establish a performancemeasurement mechanism, as performance measurement is widely established in academicliterature, it quantifies the "efficiency" and "effectiveness" of actions.

Costa et al. (2006) stated that, the construction industry worldwide adopts benchmarking initiatives to establish a PMS, with the UK's Key Performance Indicators (KPI) program launchedin 1998. The government supports this program through regional and national offices. Costa et al. (2006) discussed the implementation stages and process of KPIs, involving companies receiving a handbook, measurement guidance, and online software accessibility. Construction organizations collect, introduce, and update data, access reports, and benchmark against industry samples.

Also, performance measurement depends on the country and organizational philosophy. According to Lebas (1995), a PMS can be described as a shared vision, training, and incentives surrounding performance measurement activities. The performance measurement process could consider critical elements and feasibility analysis, while construction organizations could consider distinct variables. Table 12 provides subjective and objective measures for recording KPIs, as recommended by Chan and Chan (2004).

Construction organizations face challenges in implementing performance measurement systems due to the project-oriented nature of the industry, the need for intense effort in establishing KPIs and PMS, unclear data collection and analysis responsibilities, and distinct leadership attitudes in project management teams (Costa and Formoso, 2004).

Table 11 KIPs Objective and subjective measures

Objective Measures	Subjective measures
Construction time	Quality
Speed of construction	functionality
Time variation	End-user's satisfaction
Unit cost	Client's satisfaction
Percentage net variation over final cost	Design team's satisfaction
Net present value	
Accident rate	
Environment impact assessment scores	

8.6 Comparison to other frameworks

In order to understand the broader landscape of implementing IoT application in the construction industry, researcher will compare his own developed framework with another IoT framework that published in scientific journals recently. When comparing a framework to others, it is significant to consider both its similarities and differences. Similarities can help us understand the underlying principles or concepts that are shared across frameworks, while differences can highlight unique features or approaches that set a framework apart.

By examining both similarities and differences, we can gain a more comprehensive understanding of how different frameworks address similar problems or challenges. This comparative analysis can also help us identify strengths and weaknesses of each framework, as well as potential areas for improvement or integration. Ultimately, considering similarity and differences to other frameworks can enrich our understanding of the broader landscape of tools and methodologies available for solving complex problems and achieving specific goals. It allows us to draw on the strengths of multiple frameworks to create robust solutions that leverage the best practices from each approach.

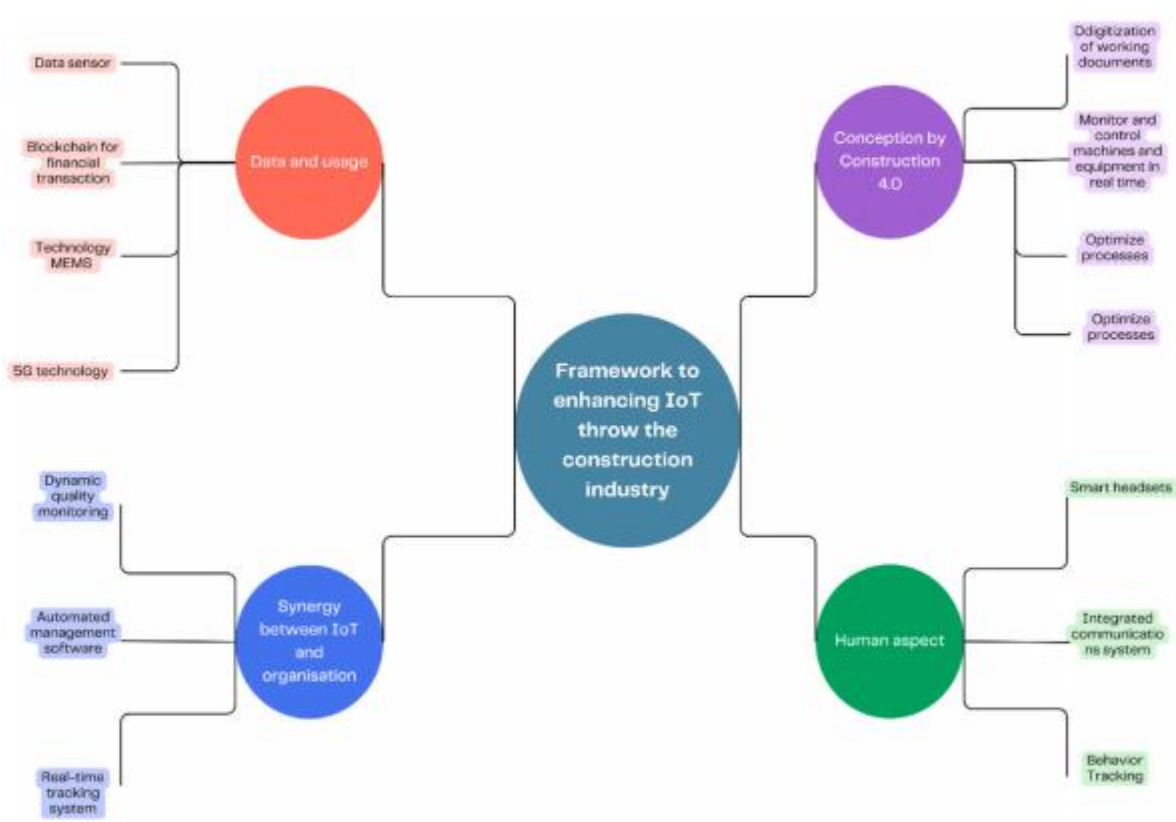


Figure 22 IoT framework development in the construction industry

Figure 22 shows the IoT framework development in the construction industry by Musarat, (2024). He argued that "The construction industry is poised for a major transformation with the advent of the IoT. It's potential to enhance construction site safety and productivity, as well as its revolutionary capabilities within its digital infrastructure, are being investigated. The construction industry is one of the sectors most affected by musculoskeletal disorders and occupational accidents, highlighting the urgent need for innovative approaches to enhance worker well-being and operational effectiveness. The IoT, with its wide range of technologies and gadgets, such as exo- skeletons, specialised clothing and adaptable tools, is positioned to play a critical role in this revolution. These solutions are designed not only to reduce the likelihood of accidents but also to improve the general working conditions of labourers (Musarat, 2024)."

Both framework are identified that there are several challenges for implementation of IoT solutions, issues such as "data security, infrastructure readiness and cost- effectiveness must be adequately addressed." Despite ongoing difficulties, the IoT is still developing albeit rapidly. Innovative technologies such as high-visibility sound vests and smart helmets with many sensors are on the horizon. In addition to addressing health and safety issues, these technologies also promise to improve coordination and communication within construction teams, ultimately leading to better project outcomes.

Both framework are agreed implanting IoT In the construction sector could boost productivity, safety, quality and sustainability across construction projects. Smart tools such as Sensors, wearables, drones and AI-based analytics are transformative technologies poised to penetrate all project lifecycle phases in the coming decade.

However, based on finding on both framework, substantial barriers around "change management, data security, investment costs and technical skills shortages must still be addressed." Therefore, construction companies should invest more funds in IoT governance and cross-departmental training while working with technology suppliers on gradual proof-of-concept deployments. Also, there is no differences between two frameworks that mostly cover each other to identify drivers and barriers for implementing the IoT in the construction industry.

In summary, the Internet of Things has the potential to make the construction industry a safer, more connected, and more productive place than it is now. A new age in construction is about to dawn, one in which job sites will be safer, smarter, and more productive via the seamless integration of technology and the real world.

8.8 Validation of the framework

Chapter 3 detailed the qualitative methodology for validating the proposed framework, which involved creating a guide in PDF format and sending it to construction professionals in the UK construction sector. Five senior project managers from the UK construction sector validatedthe developed framework. Participants provided constructive feedback through email and an online questionnaire. The validation process took place in December 2022, and the feedback was incorporated into the present framework. participant's validation process provided feedback on five aspects:

8.8.1 Feedback received from interviewees during validation process

Feedbacks are including as:

8.8.1.1 Level of understanding of the framework

Participants praised the framework's clear structure and high level of understanding.

8.8.1.2 Level of termination of the framework

Participants suggested a proper explanation of terminology and structure in the framework, including definitions for necessary terms. Also, they recommended providing a comprehensive discussion of the motivation framework's technological context.

8.8.1.3 Logic flow of the proposed framework

The framework connects concepts and actors, with participants finding the logic flow appropriate, understandable, and reasonable.

8.8.1.4 Comments and suggestions on areas that need improvement

Interviewees recommended Internet of Things (IoT) service providers could be involved in identifying construction company improvement opportunities, and the framework could include follow-up and measurement of KPIs during implementation.

8.8.1.5 Usefulness of the framework

All participants find this framework a useful approach for the initial implementation of the Internet of Things (IoT) in the construction sector and could be established in other industries.

8.8.2 Changes and final comments on the framework

The validation process's feedback has been taken into consideration when developing the framework, adding subjective and objective KPIs for implementation. Government strategic consideration of smart technology such as the Internet of Things (IoT) implementation in small companies was suggested.

The validation process raised questions for future research on Internet of Things (IoT) implementation in the UK construction sector as follows:

- Identify the convenient lifecycle phases for implementing the Internet of Things (IoT) applications in the construction industry?
- Should the Government prioritize small companies for the Internet of Things (IoT) implementation or large companies?
- Which stakeholders will be obtaining more benefits by implementing the Internet of Things (IoT) applications in the construction industry?

8.9 Summary

This chapter presented the development framework for implementing the Internet of Things (IoT) applications in the UK construction sector, considering the fragmented nature of the UK construction industry. The proposed framework includes a Persuasion-Decision framework for persuading construction companies to adopt the Internet of Things (IoT) applications and an Implementation-confirmation framework for implementing the Internet of Things (IoT) applications in the UK construction sector.

The Persuasion-decision framework encourages smart technology such as the Internet of Things (IoT) applications adoption in both external and organizational contexts, while the Implementation-confirmation framework outlines a strategic process for integrating smart tools and technology into construction projects after adopting the Internet of Things (IoT) systems.

The proposed framework in this chapter aims to develop and validate a framework for implementing the Internet of Things (IoT) applications in the UK construction sector, benefiting the government, technology consultants, stakeholders, and construction project decision-makers. The next chapter will present the research study conclusions and recommendations.

Chapter 9. Conclusions and recommendations

9.1 Introduction

Construction industry has a crucial role to the economic growth. Although, the operation of various other industries is dependent on the construction industry, this sector has the worst records in terms of safety,efficiency, profitability, and reliability (Craveiro, 2021). Through the utilisation of cutting-edge digital technology, current developments in the construction industry aim to mitigate operational inefficiencies. Innovative technologies such as Cyber-Physical Systems, Cloud Computing, Big Data, and the Internet of Things (IoT) have revolutionized the method that construction projects are designed and implemented traditionally (Ahankoob, 2021; Craveiro, 2021; Kang, 2022).

This study seeks to develop a framework for implementing of the industry 4.0 technologies such as Internet of Things (IoT) applications in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT adoption in the construction sector. For this purpose, a set of limitations exist; such as possible time constraints and approaching the knowledgeable construction professionals that are the two significant examples of existing limitations as follows:

9.1.1 Limitation of the Study

For example, some of the small construction companies could not invest to purchase digital tools and equipment to adopt and implement IoT application in their site activities because of the financial issues. So, their project managers or even their employees could not get this opportunity to be trained for using the smart technologies. Also, some of construction companies are still hesitate to adopt and implement digital tools because of the high cost of smart technologies and maintenance .Also, lack of experience and not having enough knowledge to use these smart tools could be another issue to find the knowledgeable construction professional that implemented innovative technology in their job activities. (Ahankoob, 2021; Craveiro, 2021; Kang, 2022).

On the other hand, initially, the researcher tried to use the mixed-methods by combining both qualitative and quantitative data collection that can help to validate a proper findings and provide a more comprehensive understanding of the research topic on implementing IoT applications in the UK construction sector. However, after sending the online questionnaire to more than 100 project managers that working in the UK construction sector and receiving just %10 feedback from them, the researcher decided to just focus on the qualitative research method by interviewing from the project managers in the UK construction industry to collect the proper data for analysing to get the final results. So, after collecting and analysing data, the developed framework should beuseful for construction organisations in the UK Construction sector.

This chapter will discuss the conclusions and recommendations of the research study based on the findings and results of the investigation. This chapter also presents recommendations for the body of knowledge, complemented by the body of practice, highlights future work opportunities, and discusses the research process.

9.2 Research process

This research study is aimed to develop a framework for implementation of the Internet of Things (IoT) application in the UK construction sector to assist the stakeholders to evaluate the risks and rewards of IoT implementation in the UK construction sector.

To achieve the aim of this study, the research objectives are described as follow:

1. To examine digital transformation theories and concepts and their applicability to the UK construction industry.

2. To determine the industry 4.0 approach, particularly key principles of Internet of Things (IoT) adoption across the Uk construction sector.

3. To establish the main drivers, barriers, and challenges in the process of increasing digitalisation particularly implementing the Internet of Things (IoT) application in the UK construction sector.

4. To analyse the key influencing factors for implementation of the Internet of Things (IoT) application in the UK construction sector.

5. To develop a framework for implementation of the Internet of Things (IoT) application for

stakeholders to understand the impact of IoT implementation in the UK construction sector.

6. To validate a framework for implementing the IoT applications in the UK construction sector.

The investigation utilized a pragmatic philosophy and a qualitative approach to collect and analyze data. 38 semi-structured interviews were conducted with UK construction professionals in the construction sector, recorded and transcribed. In order to analyze the interviewee's findings, a literature review was conducted to corroborate the findings. Then, the literature review was analysed using content analysis. In the following section, Key findings and conclusions for each research objective are discussed.

9.3 Contribution to the current state of knowledge

This investigation has created two significant approaches to the contributions to knowledge including theoretical and methodological, which are discussed in this section, beginning with the methodological aspect.

9.3.1 Methodological contribution

This investigation proposes the framework for understanding the key influencing factors for the implementation of the Internet of Things (IoT) integrated with smart tools into academia and data collection methodologies, incorporating 38 semi-structured interviews from the construction professionals in the UK construction sector.

Qualitative data collection, especially interviews, is challenging due to the need for elaborating questions on the same day. Social media apps such as Skype and online meeting software like Zoom are used to connect with distant individuals. However, the problem arises when new questions are discovered after processing the data, necessitating another stage of data collection. Researcher is incorporating technology into his research projects to address this issue, using WhatsApp to contact interviewees, send questions, and receive voice notes. If new questions arise, they could be contacted again to answer the questions.

9.3.2 Theoretical contribution

This section presents theoretical contributions to the research investigation that are grouped by study objectives, each addressing particular research questions.

- *Research objective 1. To examine digital transformation theories and concepts and their applicability to the UK construction industry:*

Digital transformation will be identified as the utilise of digital tools and techniques such asCyber Physical system, 3D printing, Virtual Reality, Big Data, Cloud Computing, Robotics, Internet of Things (IoT), and so on to change the nature, culture, and process of the industry's environment by providing value-producing opportunities and reshaping organizations, services, and products based cloud services.

Following the potential of digital transformation through the construction industry, digitization will be classified into four major groups based on the functions, departments, and individual divisions that are automation, digital access, digital data, and connectivity. Digital access identifies the accessibility of data by mobile tools to the local and internet networks. Digital data can be used to process and gather of data in the area of working site to achieve the real data and better usage. Automation can be identified as the innovative tools and technologies that create self-arranging schemes. Connectivity covers the function related to synchronize and link up the previously tasks.

- *Research objective 2. To determine the industry 4.0 approach, particularly key principles of Internet of Things (IoT) adoption across the Uk* construction *sector:*

Aadopting digital technology such as IoT application has an incredible impact in increasing the profitability, productivity, and faster delivery of the project in several industries. However, most of the companies are still in the process of realizing potential use cases. For this reason, the theory and idea of the innovations diffusion can be considered in industries to get the proper decision to implement the new technologies. The process of these activates are including as persuasion, decision, and then implementation.

It can conclude that the Internet of Things (IoT) applications integrated with smart tools can be utilised in various areas including security cameras, sonar surfaces and sensors, drones, GPS, tablets, smartboards, and smartphones as the main one.

- *Research objective 3. To establish the main drivers, barriers, and challenges in the process of increasing digitalisation particularly implementing the Internet of Things (IoT)* *application in the UK* construction *sector:*

The investigation identifies two key drivers for the implementation of the Internet of Things (IoT) applications integrated with smart tools in the construction industry: internal and external. Internal drivers focus on individual-oriented factors, such as productivity, management mobility, health and safety, communication, and procurement, while external drivers focus on stakeholder satisfaction, corporate transparency, environmental protection, and competitive advantage. These drivers will affect the workforce of organizations and shape their decision-making processes.

On the other hand, the investigation identifies three main challenges and barriers for the implementation of the Internet of Things (IoT) applications integrated with smart tools in the construction industry: technological challenges, cultural barriers, and economic issues. Economic challenges present the high cost of smart tools, investment issues, cost of training, hiring skilled employees, and company size, while cultural challenges address organizational culture in the construction industry. Also, in terms of technological challenges, the implementation of smart tools in the construction sector is hampered by hardware, software, and technology limitations.

- *Research objective 4. To analyse the key influencing factors for implementation of the Internet of Things (IoT) application in the UK* construction *sector:*

This investigation has highlighted the significant key influencing factors (KIFs) for implementing industry 4.0 technologies such as the Internet of Things (IoT) in the construction sector including technology awareness, size of the company, cost, leadership and management actions, and usability of the devices.

Adopting a collective mentality considering smart technology's benefits is crucial for increasing leadership in the construction sector. Also, convincing decision-makers about the benefits of implementing new tools and technologies is another key influencing factor for the successful adoption and implementation of these smart technologies in the construction business. Furthermore, enrolling decision-makers in new devices can be a good approach to promoting the adoption of smart tools and technologies such as the Internet of Things (IoT).

Construction organizations could prioritize leadership and management as crucial key influencing factors (KIFs) for implementing industry 4.0 technologies such as the Internet of Things (IoT) in their construction projects. The UK construction industry by implementing IoT tools could be able to capture and share knowledge between stakeholders, improving the communication to deliver the project on time and under budget.

Technology awareness is the other significant factor for users' perception of smart technology, emphasizing the need for education in the construction industry to better understand available smart tools and technologies. Technology consultants are required to advise construction companies on implementing and integrating new technology for projects, ensuring employee training for benefits in the workplace. They should be knowledgeable about construction industry case studies and implement the best solutions for each company size.

Construction industry professionals emphasized the importance of company size in technology investment. Small construction businesses may lack resources, while larger companies by getting more opportunities to work on multiple projects could allow the manager to better control projects and also improve communication between stakeholders and employees as a result of adopting and implementing industry 4.0 technologies.

Also, Governments could develop various case studies to assess the efficiency of Internet of Things (IoT) implementation in construction projects. This will help develop appropriate policies that promote the proper implementation of the Internet of Things (IoT) in construction projects. Government policies can play a significant role in forcing construction companies to adopt a more technological environment, motivating public and private sectors to adopt and implement industry 4.0 technology such as the Internet of Things (IoT) applications in construction projects.

- *Research objective 5. To develop a framework for implementation of the Internet of Things (IoT) application for stakeholders to understand the impact of IoT implementation in the UK* construction *sector:*

This investigation aimed to present the development framework for implementing the Internet of Things (IoT) applications in the UK construction sector, considering the fragmented nature of the UK construction industry, benefiting the government, technology consultants, stakeholders, and construction project decision-makers. The proposed framework includes a Persuasion-Decision framework for persuading construction companies to adopt the Internet ofThings (IoT) applications and an Implementation-confirmation framework for implementing theInternet of Things (IoT) applications in the UK construction sector.

The Persuasion-decision framework encourages smart technology such as the Internet of Things (IoT) applications adoption in both external and organizational contexts, while the Implementation-confirmation framework outlines a strategic process for integrating smart tools and technology into construction projects after adopting the Internet of Things (IoT) system.

- *Research objective 6. To validate a framework for implementing IoT applications in the UK* construction *sector.*

This investigation used qualitative methodology for validating the developed framework, which involved creating a guide in PDF format and sending it to construction professionals in the UK construction sector. Five senior project managers from the UK construction sector validatedthe developed framework. Participants provided constructive feedback through email and an online questionnaire. The feedback was incorporated into the present framework.

9.4 Conclusions

The investigation's findings have resulted in the following conclusions:

9.4.1 Concept of smart device

This research study defines a clear concept of industry 4.0 technologies such as the Internet of Things (IoT), providing transparency between technology researchers, project managers, technology consultants, and construction companies to adopt and implement smart technology.

9.4.2 Government culture

The UK government by encouraging stakeholders in the construction industry to adopt and implement industry 4.0 technologies such as the Internet of Things, attempts to boost productivity through cost reduction and time savings, prompting IoT and BIM implementation, and promoting the implementation of new tools and techniques.

9.4.3 Organisational culture

Organisation culture plays a significant role in developing technological innovation, considering vital elements including leadership, training staff members and development, and workforce distraction. Project location could be also a cultural challenge, however, it is an external aspect that could affect construction projects. Cultural factors obtained more important ranks than economic factors in data collection analysis as well as implementation costs or size of the company.

This investigation by analysing the data collection reveals that an "innovation culture" is crucial for successful Internet of Things (IoT) implementation in the construction industry, as it fosters an appropriate organizational culture for innovation harvesting. Actually, Innovation culture involves corporate management and stimulating creativity. It encourages creativity and shared responsibility within the organization. Canalejo (1995) claimed carious values for an innovative organizational culture, including continuous improvement, commitment to objectives, teamwork, and exemplary behavior.

9.4.4 Distraction of employees

This investigation suggests rules for defining the situation when smart tools generated distraction in the construction industry. These rules include being experienced by an organization member, generating discontinuity, internal or external factors, and being situatedin the office setting.

9.4.5 Environmental protection

Smart tools and technologies could significantly contribute to environmental protection by reducing paperwork in construction projects, making them a crucial tool for preserving the environment. The literature highlighted various numbers of construction companies implementing paperless projects (Hogan, Ghanem, 2015).

9.4.6 Pervasive Augmented Reality

Pervasive Augmented Reality (PAR) can be identified as a promising technology that could reduce errors and costs in the construction sector by offering context-aware suggestions.

However, its implementation faces challenges such as high technology costs and hardware issues. The key benefits for implementing PAR could include cost reduction, and continued assistance, while the main challenges include cost and error reduction.

Furthermore, the construction industry is poised for a promising future with the implementation of this smart technology, which could aid in visualizing technical information on construction job sites and spatial models for marketing and design.

9.5 Recommendations

9.5.1 Recommendations for academic and researchers

It could be recommended that a successful implementation case study should include a cost-benefit analysis, interoperability challenges, and user feedback. Also, this explicit knowledge could incentivize private sector decision-makers to implement industry 4.0 technology such as the Internet of Things (IoT), as they are driven by ultimate profits and willing to invest in construction solutions that enhance efficiency. Also, it is recommended that the case study would be structured and digitized, presenting accurate documented data and information to facilitate implementation.

9.5.2 Recommendations for construction companies

It could be recommended that prior to implementing the Internet of Things (IoT) applications integrated with smart tools, considering the social and technological context of the project location. Technological factors like poor internet access may require higher expenditures, while social factors like safety concerns may make it difficult for employees to carry pricy tools. Organizational culture has been identified as a significant key influencing factor (KIF) for implementing smart technologies in the UK construction industry. Furthermore, Interviewees mentioned that the organizational culture could be considered a top KIF in implementing smart technology in the construction industry.

It is a key characteristic that prompts innovation in technology. To change organisational culture in the construction industry, organisations must be prepared to take risks, innovative and client-oriented, and provide opportunities for their employees to communicate properly. These actions can be applied to any industry, not just construction companies.

9.5.3 Recommendations for the government

It could be recommended that to encourage large construction organizations to adopt and implement industry 4.0 technology such as the Internet of Things (IoT) applications, the government should implement regulations and subsidize small companies. The proposed framework in Chapter 9 could develop guidelines for implementing smart tools in the infrastructure sector while the feasibility analysis in section 8.6.2.3 evaluates scenarios when construction organizations could implement smart tools and technologies, both could be usedby government.

9.6 Future research

In terms of the future research based on this research study, it will recommended that case study should be applied by implementing the proposed framework for implementing the IoT applications and then validate it in the construction sector as because of the time limitation, the researcher could not include a case study in this research.

Also, on chapter 8's framework validation process, participants raised questions about the implementation of smart technology in the construction industry, Actually, those questions were about on which phases of the construction life cycle benefit the most from smart technology implementation, requiring it to be addressed.

Also, it will be useful to compare this proposed framework in the different countries to assess the cultural barriers and how impact on improving the performance of the construction sector.

The other future research should be applied about the integration of the IoT with other industry 4.0 technologies in order to improve the construction productivity.

Furthermore, future research should focus on gathering and comparing case studies of successful Internet ofThings (IoT) applications implementation in different countries with several socio-economic situations. These findings could be associated with a developed framework for implementing Internet of Things (IoT) applications in the construction industry, particularly in the infrastructure sector.

This research investigates the significant drivers, challenges, and cultural factors for implementing Internet of Things (IoT) applications in the Uk infrastructure sector. It highlightsthe differences between cultural factors like uncertainty, followed by collectivism, and then individualism. Future research should explore these aspects to better understand the implementation of Internet of Things (IoT) applications in the construction industry.

The investigation highlights the challenge of employee distraction when implementing smart devices such as tablets or smartphones, as highlighted by McBride (2015). Mobile devices can disrupt primary tasks and create workforce discontinuity. Analysis of the distraction caused by smart devices in the construction sector should be considered for future research.

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