IMPLEMENTATION OF SMART DEVICES IN THE CONSTRUCTION INDUSTRY

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PhD thesis 2019

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A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton for the degree of Doctor of Philosophy (PhD)

October 2019

This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless otherwise indicated). Save for any express acknowledgements, references and/or bibliographies cited in the work, I can confirm that the intellectual content of the work is the result of my own efforts and of no other person.

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Date _______________________________

Abstract

The construction industry has a fragmented nature, which accounts for the highest degree of decentralisation of information and the highest mobile content access. The exchange of information made possible by smart devices. This creates an opportunity to enhance productivity and communication among stakeholders of the construction industry. Firstly, this thesis explored the concept of smart devices. Secondly, the drivers, challenges and Critical Success Factors for implementing smart devices were investigated. This study adopted a qualitative approach using semi-structured interviews. A total of Thirty-nine interviewees which includes professionals from the construction sector of the Dominican Republic (DR) and the United Kingdom (UK) were interviewed. Thematic analysis was used to analyse the collected data. The drivers for the adoption of smart devices were grouped into internal and external drivers. The challenges found in the interviews were grouped into three categories, namely, economic, cultural and technological. The Critical Success Factors (CSFs) for implementing smart devices in the construction industry are leadership, training and development, organisational culture, technology awareness, cost, company size and usability. These findings were used to develop a strategic framework which has two sub-frameworks. This study concluded that a specific culture must be adopted on behalf of the government and construction companies to successfully adopt smart devices. Furthermore, this investigation found various similarities and differences regarding the drivers, challenges and CSFs for implementing smart devices in the UK and the DR. This study recommends integrating smart devices in data collection techniques in academia. Also, for construction companies to embrace technological innovation it is recommended to be willing to start new ventures, to be open to the participation of all members of the company, and be creative and client-oriented.

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Acknowledgements

I wish to thank the government of the Dominican Republic for providing the financial support required to make this thesis possible.

I would like to express my gratitude to my Director of studies, Dr. Suresh Renukappa, for the time he invested in meeting with me and pushing this thesis forward. I would also like to thank my second supervisor, Dr. Subashini Suresh for her insightful comments and revisions that helped this thesis achieved its best shape.

I thank Alexandra Kardakou for her great support during the data collection process of this dissertation. Her help was a key factor in achieving the milestones of this investigation.

I would like to thank my friends and PhD colleagues for being great advisors in adverse and good times. Their clear perspective of things gave me good guidance when I did not know which path to choose. Our discussions helped me to clarify many things and draw a better understanding of my thesis. Their suggestions and ideas were very insightful.

Finally, but by no means least, thanks go to my family: My parents, brother and wife. To my parents, Gisela Dolores Fernández Pérez and Marcelino Silverio Vásquez, for always believing that I am the best in whatever I commit to do, they actually made me believe that too. To my brother, Albert Marcelino Silverio Fernández, for believing in me and knowing how to make fun out of most situations. To my wife, Kamila Silverio Fernández, for giving me constant support and always believing in me, even when I did not.

Dedication

This thesis is dedicated to:

My parents, Gisela Dolores Fernández Pérez and Marcelino Silverio Vásquez. My brother, Albert Marcelino Silverio Fernández. And my wife, Kamila Silverio Fernández.

Thanks for believing in me.

Declaration

All research has been conducted by the PhD candidate and no portion of the research referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institution of learning.

List of abbreviations and acronyms

Abbreviation	**Acronyms**
ABI	Allied Business Intelligence
AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
CC	Cloud Computing
CV	Computer Vision
DL	Deep Learning
DR	Dominican Republic
EnHANTs	Energy Active Networked Tags
GDP	Gross Domestic Product
GIS	Geographical Information System
HS1	High Speed 1
HS2	High Speed 2
IoNT	Internet of Nano Things
IoT	Internet of Things
IoUT	Internet of Underwater Things
LAC	Latin America and the Caribbean
MC	Mobile Computing
MCC	Mobile Cloud Computing
ML	Machine Learning
NIST	National Institute of Standards and Technology
NLP	Natural Language Processing
P&G	Procter & Gamble
RFID	Radio Frequency Identification
RFIDs	Radio Frequency Identification systems
ROI	Return of Investment
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
WSN	Wireless Sensor Network

Research Output

Book Chapters

- Silverio, M., Renukappa, S., Suresh, S. and Donastorg, A. (2017) Mobile Computing in the Construction Industry: Main Challenges and Solutions. *in Leadership, Innovation and Entrepreneurship as Driving Forces of the Global Economy.* Springer.

Journal Articles

- Silverio, M., Renukappa, S. and Suresh, S. (2019) Evaluating critical success factors for implementing smart devices in the construction industry: An empirical study in the Dominican Republic. *Journal of Engineering, Construction and Architectural Management*.
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- Silverio, M., Renukappa, S. and Suresh, S. (2018) What is a Smart device? **-** A conceptualisation within the paradigm of the Internet of Things. *Journal of Visualization in Engineering*.

Conference proceedings

- Silverio, M., Renukappa, S. and Suresh, S. (2017a) Implementation of smart devices in the Dominican Republic construction industry: An empirical study. *Salford University International Research Conference (IRC)* pp. 656.

- Silverio, M., Renukappa, S. and Suresh, S. (2017b) Pervasive Augmented Reality in the Construction Industry: Barriers, Drivers, and Possible Applications. *International conference on Sustainable Futures*.
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Chapter 1: Introduction to the study

This chapter introduces this investigation by presenting the background and justification for this study. Then, the research aim, objectives and research questions of this project are presented. Furthermore, this chapter highlights the benefits of this research as well as the structure of the thesis.

1.1 Background to the research

In order to understand the purpose and context of this investigation it is necessary to understand the key challenges surrounding the construction industry as well as their solutions and how they linked to smart devices. Crotty (2013) highlighted two key strategic challenges for the construction industry, namely, inability to complete projects predictability and low level of profitability. These issues are considered of first order of importance. Other challenges such as sustainability, productivity, collaboration and safety are considered as second order issues, since they are not vital to the survival of construction organisations. The solution shown by Crotty (2013) consisted on improving communications in the industry. To achieve this, it is suggested that nature and quality of information is improved by focusing on organisational structures and information exchange.

Before attempting to improve information exchange in construction firms it is worth mentioning that the construction industry has the highest degree of decentralisation of information among five different industries, namely: Manufacturing; construction; financial services; media and entertainment and software (Box, 2014). This indicates how information is distributed within construction organisations. Another important variable measured by (Box, 2014) is mobility. According to this study the construction industry has the highest rate of mobile content access, this resulting in stakeholders interacting and accessing content via mobile devices more than any other sector analysed by this study. The last variable where the construction sector has the first place is external collaboration; this results in a high rate of subcontracting and interaction between workers.

Now we need to consider the Internet of Things (IoT) and smart devices. IoT is a relatively recent paradigm that is rapidly gaining ground and acceptance in the scenario of wireless telecommunications. This concept is based on the continuous presence of a diversity of objects which are connected to a network or other devices and can interact with each other to reach common goals (Giusto *et al*, 2010). The main strength of the IoT is the high impact it will have on several aspects of everyday life and behaviour of potential users in both working and domestic fields. If well implemented in the field of Construction it represents a major step towards the integration of stakeholders via autonomous information exchange.

Smart devices are a crucial part of the IoT. They are in fact the Objects or Things interconected by this paradigm, as explained by Stojkoska and Trivodaliev (2017).

According to Atzori *et* al. (2010), the IoT has an enormous potential for developing a large number of applications in our society. By implementing this paradigm in the construction industry, regular objects would record data which can be used to build relevant metrics to users. The data obtained from the integration of the IoT with traditional construction processes can be used to enhanced construction projects, and subsequently, make the industry more sustainable, by enabling regular objects to communicate with each other and collect information from the surroundings where a wide range of autonomous applications can be deployed.

It can be expected that smart devices contribute to improving the information exchange in the construction industry, which as mentioned before would help to address the key issues explained by Crotty (2013).

In addition, smart devices enhance mobility and communication in any industry, and nowadays trends of sustainable construction show as necessary the implementation of the latest technologies to improve the construction sector. It seems appropriate that the exchange of information made possible by smart devices and the IoT creates an opportunity to enhance the construction sector, thus increasing sustainability.

Construction firms have already started to integrate smart devices into their projects. As the implementation of mobile technologies and cloud computing has increased in the last decade and new mobile technology users are arising every day; Entrepreneurs are creating Information Technology (IT) solutions based on mobile technologies in different fields (e.g. medicine, construction, teaching, etc.). Consequently, This has made researchers in the construction sector to start embedding mobile solutions into construction projects.

Chen and Kamara (2011) was the first to develop a framework for implementing mobile computing for information management on construction sites. Two models were developed, first an application model which explores the interaction between mobile computing, construction personnel, construction information and construction sites; second a technological model which ultimately provides a structure for designing mobile computing systems.

Prior to this framework some early attempts of implementation of mobile computing technologies in construction processes include: developing an automated construction activity monitoring system based on a mobile computing communication (Rebolj *et al*., 2008); security and safety of wireless network (Strachan and Stephenson, 2009); and CAD visualization on mobile devices (Yang *et al.*, 2009). These and others early attempts led to a categorization into five different areas made by Kim *et al.* (2013):

1. Development of a framework or platform to demonstrate how mobile computing should be used for construction.
2. Mobile computing as a tool for identification or general construction management.
3. Mobile computing for defect management.
4. Mobile computing for safety or disaster management.
5. Development of specific features of mobile.

Aware of these categories Kim *et al.* (2013) developed an on-site management system using mobile computing technology, to reduce cost and time of information transfer and improve work efficiency. Three main components of the system were: site monitoring, task management and real-time information sharing. The study proved that the proposed mobile system is expected to improve the performance of existing on-site management processes by reducing construction time and cost; and increasing the quality of a construction project.

The construction industry is changing an image of late innovation by adopting mobile solutions into the construction operations. According to Azhar and Cox (2015) at the end of 2013 there were approximately 13,000 design and construction apps available, whereas there were approximately 230 apps of this kind in 2011.

In the Southeast of the United States Azhar and Cox (2015) explored 88 construction firms that are using mobile solutions from at least 3 years, finding that the most used mobile hardware on construction sites are iPads (49.1%), followed by iPhones (45.7%), blackberry phones (38.2%) and android phones (32.7%). Some applications given to mobile solutions were: site photos, punch lists preparation, existing condition documentation, safety comments, scheduling, BIM Coordination, project closeout documentation, employee attendance, etc.

1.2 Justification of the study

The IoT is proliferating across all sectors, creating opportunities and becoming a competitive marketplace weapon as the focus of primary benefits, shifts from both internal and external improvements of the worldwide industries (Gartner, 2016). Various sectors benefitted from the IoT are: design and construction, transportation, smart city, smart homes, smart health, e-governance, assisted living, e-education, retail, logistics, agriculture, automation, industrial manufacturing, and process management (Gubbi, et al, 2013) and (Miorandi*, et al*., 2012).

In 2011 Cisco predicted that 50 billion of Things would be connected to the Internet by 2020 (Evans, 2011). On the other hand, more recent investigations show that 25 billion devices will be connected to the internet by 2020 and those connections aim at facilitating the process of autonomous intelligent decision making (Gartner, 2014). Regardless, which prediction is more accurate, there will certainly be more smart things than the estimated world population.

The importance of the IoT relies on its size, which is expected to surpass the size of the Internet, subsequently it is also expected to surpass it in terms of importance and revenues.

In the early days of this investigation the experts forecasted the following estimated projected size of the IoT:

- Gartner research firm estimates that IoT will connect close to 26 billion devices by 2020 (Gartner, 2014).
- Allied Business Intelligence (ABI) Research says the number will be more than 30 billion by 2020 (Allied Business Intelligence, 2013).
- Cisco prophesizes 50 billion devices by 2020 (Evans, 2011).
- Nielsen Research says 100 billion devices by 2020 (Nielsen research, 2015).
- Intel says 200 billion devices by 2020 (INTEL, 2015).
- International data corporation (IDC) says 212 billion devices by 2020 (International Data Corporation, 2013).

In reality some of these predictions are correct, whereas others are excessive. By 2019, the number of IoT devices was 26.66 billion, expected to be 30.73 in 2020, and 75.44 in 2025 (Statista, 2019).

By September 2017 the Internet users in the world were around 3.88 billion, that is 51.7% of the world population on the same date. By 2020 there will be much more connected devices than people on the Planet.

According to Atzori *et* al. (2010), the IoT has an enormous potential for developing many applications in our society. By implementing this paradigm in the construction industry, regular objects would record data which can be used to build relevant metrics to users. The data obtained from the integration of the IoT with traditional construction processes can be used to enhance construction projects efficiency, and subsequently, make the industry more sustainable, by enabling regular objects to communicate with each other and collect information from the surroundings where a wide range of autonomous applications could be deployed.

Smart devices are objects capable of communication and computation which range from simple sensor nodes to home appliances and smartphones. This investigation considers smart devices as the objects present in a pervasive network of the IoT (Stojkoska and Trivodaliev, 2017). Some authors also use other terms when referring to smart devices, Azhar and Cox (2015) use the terms “mobile tools”, “mobile technologies” and “mobile devices” for devices that allow professionals to get instant access to project documents, plans and specifications.

The main strength of the IoT is the high impact it will have on several aspects of everyday life and behaviour of potential users in both working and domestic fields. If effetively implemented in the field of Architecture, Engineering and Construction (AEC) it represents a major step towards the integration of stakeholders via autonomous information exchange.

The construction sector is information-intensive due to various piece of crucial data that need to be transferred and exchanged during a project’s lifecycle Chen and Kamara (2011). In 2015, research had already shown an upswing in the adoption of smart devices in construction project (Sattineni and Schmidt, 2015).

The implementation of smart technologies and the paradigm of the IoT in a business enhances factors like productivity, quality, cost and time (Kim *et al.* 2013), (Falk and Leist, 2014) and (Azhar and Cox, 2015). Nevertheless, there is a lack of an integral and scalable framework for the implementation of smart devices in the construction industry that can provide guidelines for multiple global scenarios.

Despite Chen and Kamara (2011) developed a framework for using mobile computing for information management on construction sites, such work does not address a general set of guidelines for implementation of smart devices. Instead it only focuses on a general view/description of the mobile computing system in construction projects. This investigation proposes the construction industry needs to establishing guidelines which allow the standardisation of the implementation of smart devices.

1.2.1 The Dominican Republic construction industry

The Dominican Republic (DR) is located in the heart of the Caribbean, where it is exposed to natural phenomena such as hurricanes, flooding and earthquakes. Consequently, the country’s infrastructure must be designed to withstand such adverse weather and natural conditions (United Nations Environment Programme, 2013). This represents a challenge for professionals within the field of AEC sector regarding coordination, management and quality assurance. The construction industry of this country has been the most significant economic activity in the country, providing employment and economic growth. According to the report on the economy of the DR (Central Bank of the Dominican Republic, 2016) on a national scale, the construction industry contributes approximately 18% of the Gross Domestic Product (GDP) and has had one of the highest economic relevance for twelve trimesters. This economic behaviour is due to the necessity of dwellings of low cost and execution of public and private projects focused on tourism, commerce and road work.

In a broader context, the DR is intertwined with the Latin American economy, interacting with major players such as México and Brazil, which according to Hoffmann *et al.* (2017) have the highest GDP in the region. According to The World Bank (2018) The Dominican Republic's economic growth has been one of the strongest in the Latin America and Caribbean (LAC) region over the past 25 years. With a GDP of 71.8 billion US dollars by 2017, the economy of the DR surpasses that of Costa Rica, which has a GDP of 57.43 billion US dollars by 2017. Although, there are major players like Mexico and Brazil with a GDP of 1.047 and 1.796 Trillion US dollars respectively (The World Bank, 2018).

There is a lack of research and information exchange regarding the construction industry in Latin-American nations. Therefore, it is a challenge for this research to establish a clear comparison about the implementation of smart devices in the construction industries of distinct Latin American nations.

By addressing the implementation of Smart devices in the construction sector of the DR this study provides an insight into the key factors to consider in developing countries of this nature. Due to the vital role, this sector represents, and since no background study of this type exists in the area of the Caribbean, it results necessary to develop strategies for embedding new technologies such as smart devices and the paradigm of the IoT within the construction industry.

1.2.2 The United Kingdom construction industry

Construction is a very diverse industry that includes activities ranging from mining, quarrying and forestry to the construction of infrastructure and buildings, the manufacture and supply of products, as well as their maintenance, operation and disposal.

According to the report “Digitally Built Britain” (HM government, 2015), the United Kingdom (UK) construction industry indirectly employs over three million people. It delivered around £69 billion to the UK economy in 2010 and is a key contributor to UK growth. It also has a critical role in meeting the UK climate change targets.

Construction output in the UK is more than £110 billion per annum and contributes 7% of GDP (Cabinet office, 2011). Approximately a quarter of construction output is public sector and three-quarters is private sector.

According to Cabinet Office (2011) there as three main sectors in the field of construction: commercial and social (45%), residential (40%), and infrastructure (15%).

The UK government committed to reduce greenhouse gas emissions by 80% by 2050 compared to 1990 levels, and to reduce them by half by 2025. In 2009 buildings accounted for around 43% of all the UK’s carbon emissions (HM Government, 2010).

In July 2013, the UK government published the report “construction 2025, Industrial Strategy: government and industry in partnership” (HM Government, 2013). In this document the UK government proposes its long-term vision for the construction industry, aiming at performing massive reductions in cost, greenhouse gas emissions, overall construction time, and other variables. More specifically the 2025 agenda sets out five main components:

- SMART: An industry that is efficient and technologically advanced.
- PEOPLE: An industry that is known for its talented and diverse workforce.
- SUSTAINABLE: An industry that leads the world in low-carbon and green construction exports.

- LEADERSHIP: An industry with clear leadership from a Construction Leadership Council.
- GROWTH: An industry that drives growth across the entire economy.

It appears to be plenty of evidence of the leadership of the UK government towards a more efficient construction industry. Smart devices are already being implemented in this industry. In the context of the UK, this investigation should understand what the drivers, challenges and critical factors around a successful implementation of smart devices in the construction industry are.

1.2.3 Smart devices and the fourth industrial revolution

Smart devices play a crucial role in the fourth industrial revolution, also known as Industry 4.0. The paradigm of Industry 4.0 aims at introducing a new level of organisation and control within the current industry, thus taking the last industrial revolution to a new level of efficiency. Figure 1.1 shows the four industrial revolutions in human history and locates the Industry 4.0 within a chronological context. Each industrial revolution was separated by a hundred years. Differently, the industry 4.0 comes after only half a century. The term Industry 4.0 is regarded as a fourth industrial revolution which defines a new level of organisation and control over the entire value chain of the life cycle of products Rüßmann *et al.* (2015). The central objective of Industry 4.0 is fulfilling individual customer needs which affect areas such as management, research and development, manufacturing, utilisation and recycling of products.

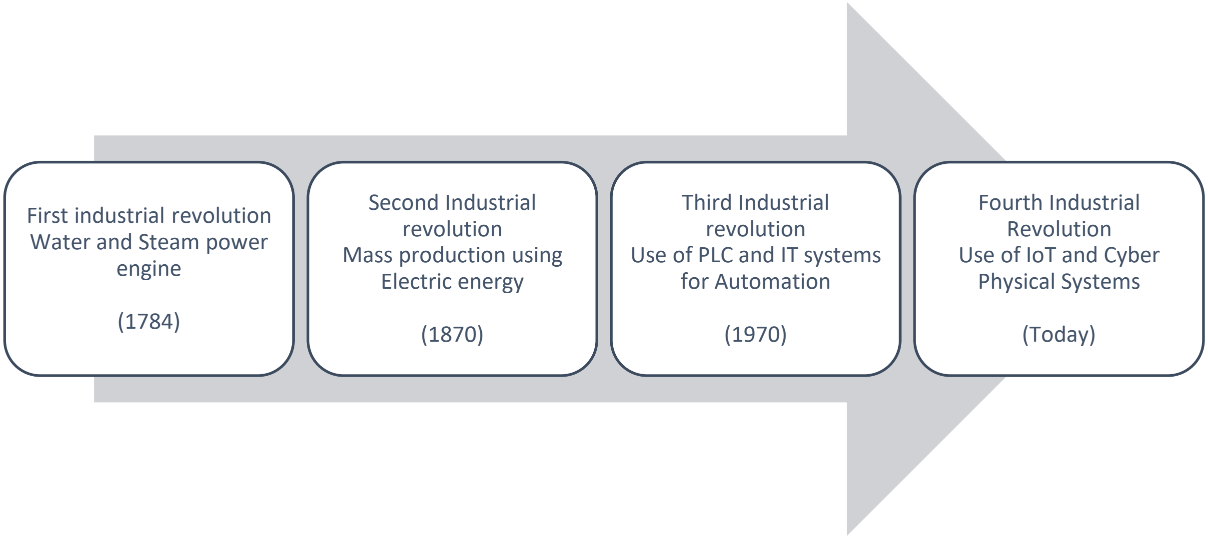

Figure 1.1: Four industrial revolutions

One of the key players in this revolution is smart devices. Stojkoska and Trivodaliev (2017) highlight smart devices as the core devices present in the IoT. Smart devices are used in the IoT to collect and analyse data, thus gathering relevant data for different industries in the Built and natural environment. According to Lee, Kao and Yang (2014), the industry 4.0 relies on the IoT for converting regular machines to self-aware and self-learning machines, hence improving their overall performance and interaction with the environment.

To help with the implementation of the IoT into the different industries on a worldwide level, several investigations have already contributed frameworks and toolkits for development of Smart cities through the implementation of the IoT. Some examples are:

- An information framework for creating smart city through the implementation the Internet of Things (Jin *et al*., 2014).
- Building a Framework for Internet of Things and Cloud Computing (Anon *et al*., 2014).

1.3 Research aim and objectives

1.3.1 Research aim and objectives

The overall aim of this research is to develop a strategic framework for implementing smart devices in the construction industry. Such framework must provide a holistic and systemic approach which guides users towards the implementation of mobile apps in the construction sector. To achieve this aim, the following objectives were identified.

1. To establish a clear definition of the concept “smart device”
2. To explore the adoption of smart devices in construction projects.
3. To investigate the drivers for implementing smart devices in the construction sector.
4. To explore the challenges for implementing smart devices and the paradigm of the IoT in the construction industry.
5. To survey the critical factors for a successful implementation of smart devices in the construction industry.
6. To develop and validate a strategic framework for the implementation of Smart devices in the Construction industry.

1.3.2 Research questions

1. What is a smart device?
2. Which smart devices are used in the construction industry?
3. What are the utilisations given to smart devices in construction projects?
4. What are the drivers that have fuelled the implementation of smart devices in construction projects?
5. What are the challenges that the construction industry faces for implementing smart devices?

6. What are the critical success factors for implementing smart devices in the construction industry?

The research questions and objectives mentioned above are linked in the matrix showed in Table 1.1.

Table 1.1: Matrix of linkage between research objectives, research questions, chapter addressed and research techniques

No.	Research Objective	No.	Research Questions	Chapter addressed	Research technique for data collection
RO1	To establish a clear definition of the concept "smart device"	RQ1	What is a smart device	Chapter 4	Literature review
RO2	To explore the adoption of smart devices in construction projects.	RQ2	Which smart devices are used in the construction industry?	Chapter 5	Semi-structured interview
		RQ3	What are the utilisations given to smart devices in construction projects?		
RO3	To investigate the drivers for implementing smart devices in the construction sector.	RQ4	What are the drivers that have fuelled the implementation of smart devices in construction projects?	Chapter 6	Semi-structured interview
RO4	To explore the challenges for implementing smart devices and the paradigm of the IoT in the construction industry.	RQ5	What are the challenges that the construction industry faces for implementing smart devices?	Chapter 7	Semi-structured interview
RO5	To survey the critical factors for a successful implementation of smart devices in the construction industry.	RQ6	What are the critical success factors for implementing smart devices in the construction industry?	Chapter 8	Semi-structured interview
RO6	To develop and validate a strategic framework for the implementation of Smart devices in the Construction industry.	Framework		Chapter 9	Semi-structured interview

1.4 Contribution to knowledge

The study will benefit the employees, decision makers and policy makers of the construction industry by providing a framework for a strategic implementation of smart devices and the paradigm of the IoT in construction projects. This framework will result in:

- Providing a scalable definition of the term "smart device"
- Assisting decision makers to identify their level of implementation and the subsequent stages in implementing smart devices.

- Providing an information flow between companies within the construction industry and technology consultants for the provision of adequate technological solutions for companies.
- Improving awareness of the digitalization of processes in construction companies.
- Improving awareness of the drivers for implementing smart devices in construction projects.
- Improving awareness of the challenges for implementing smart devices in construction projects.
- Explaining the utilizations given to smart devices in the construction sector.
- Providing a list of smart devices used in construction companies.
- Explaining the Critical factors for a successful adoption of smart devices.

The outcomes of the study have been published in three peer-reviewed journal papers and five conferences attended by academics and practitioners. This process allowed for enhancement of improvement in the research techniques used for this investigation.

1.5 Research scope and limitations

This study performed an empirical analysis in construction companies within the construction industry of the DR and UK. Subsequently, this is a comparative study which collects its data from the DR and UK. These two countries have different socio-economic situations and will provide a wider frame regarding the construction industry in developing and developed countries. The rationale for doing a comparative study is further explained in Chapter 3: Research methodology.

The research performed in this study is exploratory in nature. This is due to the nature of the topic area being researched and the lack of background research in this area. The goal of this research is to answer the research questions rather than testing hypothesis. A pragmatic research philosophy was selected for this research. According to the definition of pragmatism given by Emirbayer and Maynard (2011) the researcher must be flexible with the selected methods and techniques. Instead of applying a single accepted research method, a pragmatic researcher would leave the theory guide the investigation (Strang, 2015). One important difference between a pragmatic and constructivist approach is that in the first the researcher interprets whilst in the latter the participants interpret.

As explained by Yehevis *et al. (2013)*, a construction project contains three key phases. Pre-construction, construction and renovation, and demolition (See Figure 1.2). This investigation considered the implementation of smart devices during the construction phase of the construction lifecycle. On this stage construction companies are mainly involved with Design, Material management and construction practice (Yehevis *et al., 2013)*.

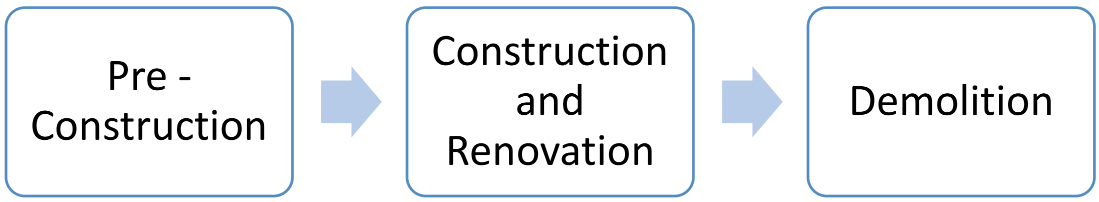

Figure 1.2: Construction lifecycle. Adapted from Yeheyis et al. (2013)

The unit of analysis adopted for this study is the ‘construction sector’ and the sub-unit is ‘individual employee’ who is involved in the implementation of smart devices in construction projects. Due to the pragmatic philosophy behind this study, the comparison between micro, small, medium and large companies are made despite the selected unit of analysis.

The main outcome of this investigation is a strategic framework for implementing smart devices in the Construction industry. This framework has been validated with experienced professional. Nevertheless it has not been tested within an organisation.

1.6 Thesis structure

The layout of the thesis is in a logical sequence, commencing with the introduction to the investigation in chapter 1 to the conclusions and recommendations in chapter 10. To start understanding the structure of this thesis Figure 1.3 presents a visual representation of the thesis structure which indicates the organisations of the thesis. Following the structure in Figure 1.3 chapter 2 shows the literature review conducted to draw an understanding on smart devices and their implementation in the construction industry. Then the research methodology is presented in Chapter 3. Chapter 4 presents a definition of smart device within the paradigm of the Internet of Things. The findings from the data collection and analysis are presented in chapter 5 to 8 which can be read in any order. Chapter 9 illustrates and describe the framework developed by this investigation. Finally, chapter 10 discusses the conclusions and recommendations of this thesis.

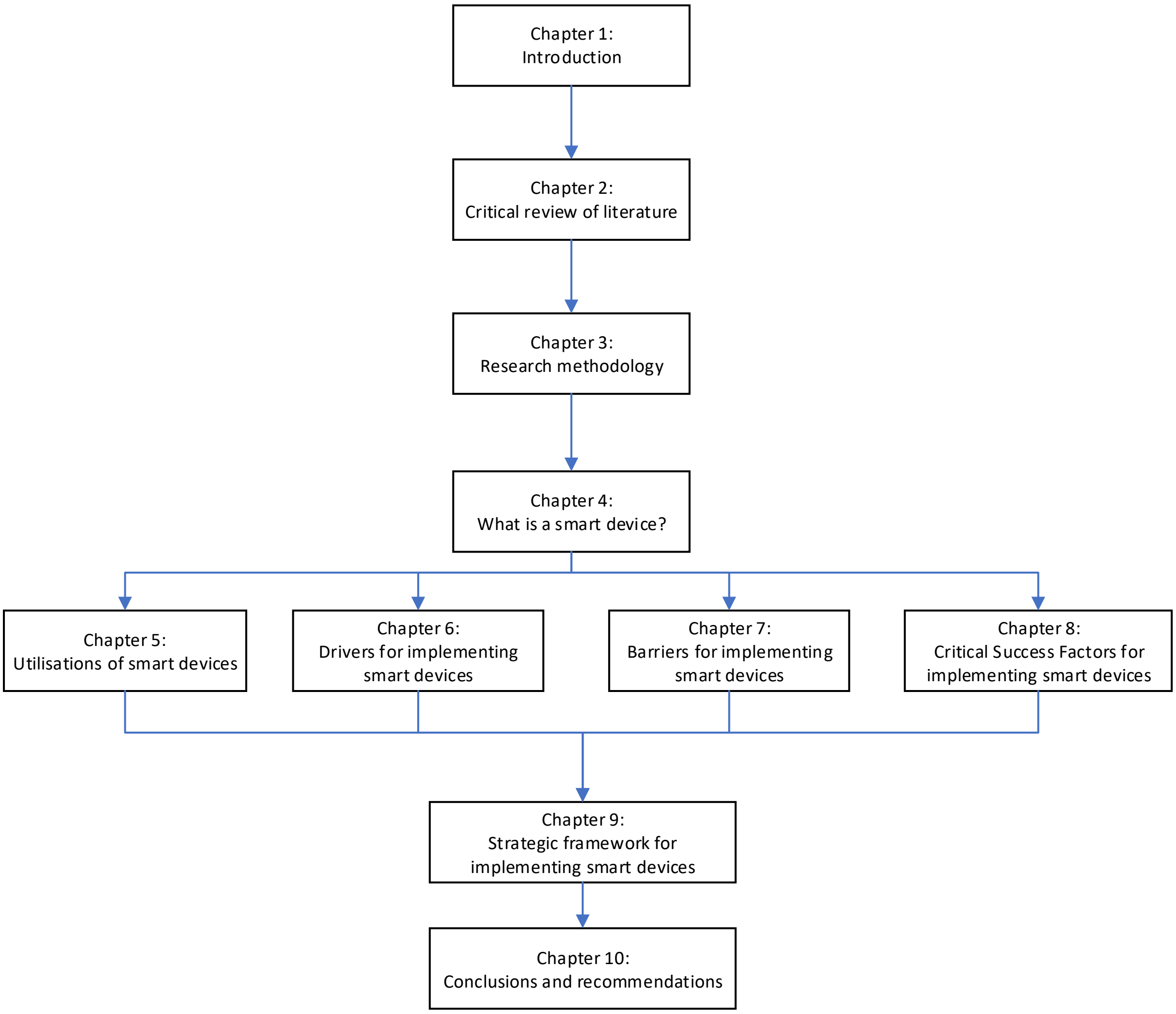

Figure 1.3:Thesis structure diagram

Following this summary of the structure of this thesis, a more detailed explanation is provided regarding the content of each chapter:

Chapter 1: Explains the research aim and objectives of the study. It also, addresses the background, justification, benefits, scope and limitations of the study.

Chapter 2: Following the introduction, the second chapter reviews the relevant literature on the subject of study.

Chapter 3: Explains the research methodology used to answer the research questions of this investigation. This chapter discusses the underlying research philosophy of this research as well as the research process implemented to empirically gather the perception of the construction industry. The research methods and instruments utilised are individually addressed.

Chapter 4: Presents a definition of Smart device based on a literature view. This chapter presents the terminology found in the literature for addressing smart devices as well as key features found in smart devices.

Chapter 5: Discusses the adoption of smart devices in the construction industry of the UK and the DR. This chapter addresses the level of adoption of smart devices in the construction industry as well as the typical smart devices used in the industry.

Chapter 6: Presents the drivers for implementing smart devices in the construction sector. The results of 39 semi-structured interviews from professionals in the field of Construction of the DR and UK.

Chapter 7: Presents the barriers or challenges for implementing smart devices in the Construction industry based on 39 semi-structured interviews. The results are supported with the existing literature.

Chapter 8: This chapter discusses the Critical success factors for implementing smart devices in the Construction industry. The findings are discussed against the relevant literature.

Chapter 9: Introduces and discusses a strategic framework for successfully implementing smart devices in the construction industry. The findings from previous chapters were considered in the development of the framework. The developed framework provides a better understanding of the driving and restraining forces for implementing smart devices in the construction industry.

Chapter 10: reports the conclusions and recommendations obtained from this investigation. It summarises the findings and challenges of this research and makes inferences based on this knowledge. This chapter provides recommendations for future research related to IoT, smart cities and Industry 4.0.

Chapter 2: Review of literature on Smart devices, Internet of Things and their role in the construction industry

2.1 Introduction

This chapter presents a thorough critical review of the literature on smart devices and the paradigms and technologies associated to the implementation of smart devices in the construction industry. The following sections describe distinct paradigms and technologies and their relationship with the IoT and smart devices.

2.2 Definition of smart devices

One of the first challenges in this research was the lack of a clear concept of smart device. Across the literature, different terms are found for what this investigation calls smart devices.

Lo *et al.* (2014) used the term smart device, whereas (İlhan *et al.*, 2016) used the term smart mobile device. The term mobile devices is also used by some authors, such as (Lau *et al*, 2017; Khan and Khan, 2017; and Furthmüller and Waldhorst, 2012).

Azhar and Cox (2015) use the terms “mobile tools”, “mobile technologies” and “mobile devices” for devices that allow workers to get instant access to project documents, plans and specifications. Azhar and Cox (2015) address tablets, cloud technologies, Radio Frequency Identification Tag (RFID) and wearable devices as mobile technologies when tablets, smartphones and wearables are devices that implement various mobile technologies. This misconception is led by the lack of a clear concept of smart device.

The literature review showed an inconsistent terminology, many authors used the term “mobile device” for addressing smartphones, tablets and wearables. Other authors use the term “smart device” to referring to the same devices. Chapter 4 presents the results of a methodological approach to create a concept for smart device. The following definition can also be found in Silverio-Fernández *et al.,* (2018):

> *“A smart device is a context-aware electronic device, capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange.”*

This investigation considers the following features for a device to be considered as smart: Autonomy, connectivity and context-awareness. These are the key features that authors in the literature allocate to smart devices are furtherly discussed in chapter 4.

2.3 Paradigms and technologies associated to smart devices

The thorough investigation revealed various paradigms and technologies and their relationship to smart devices. The starting point from this investigation was smart devices in construction. This concept led to finding major paradigms that encompass smart devices and their implementation in any industry. Figure 2.1 shows the concepts found in the literature review; in this diagram it is observed the IoT as the paradigm that holds the concept of smart device how it is linked to other paradigms such as Big data, Artificial intelligence (AI), Building Information Modelling (BIM), Cloud Computing (CC) and Mobile Computing (MC).

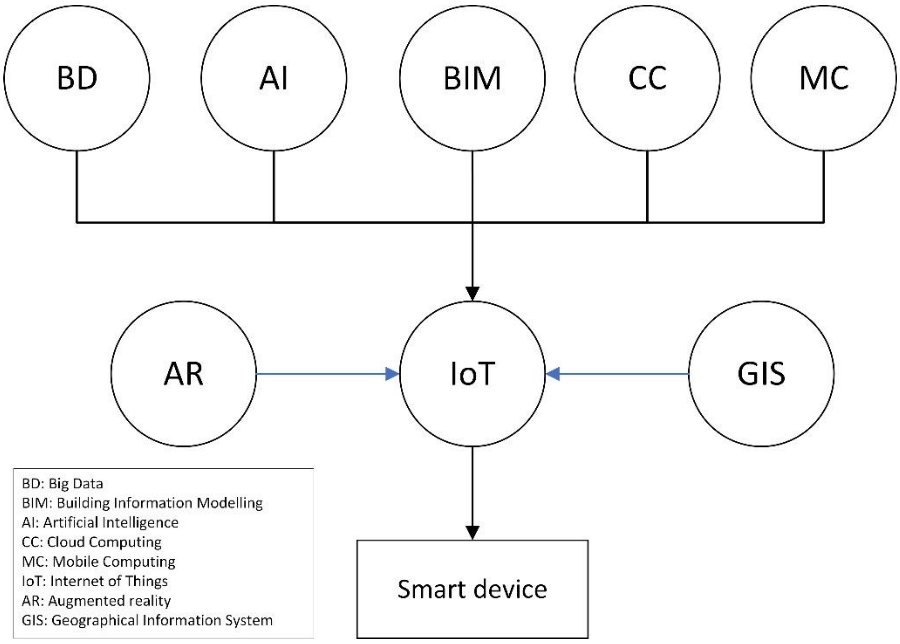

Figure 2.1: Paradigms and technologies associated to smart devices

The relationship between these paradigms is discussed in the following sections. First the IoT is presented, followed by AI and Big Data, which are presented together in section 2.5. CC and MC are discussed together in section 2.6. BIM has brought a revolutionary workflow into the construction industry, and smart devices being part of this change. Section 2.7 explains the dynamic between BIM and smart devices. The relationship between smart devices and Augmented Reality (AR) and Geographical Information System (GIS) is further discussed in sections 2.8 and 2.9 respectively.

2.4 Internet of Things, Smart cities and Industry 4.0

2.4.1 What is the IoT: Definition and building blocks

The term Internet of Things was coined in 1999 in a presentation at Procter & Gamble (P&G) by Kevin Ashton; who envisioned linking Radio Frequency Identification systems (RFIDs) and sensors to the Internet such that data about objects in the world is obtained by computers without being limited to human-provided data (Ashton, 2009).

Smart devices can be considered as the “Things” or “objects” within the network of interconnected devices known as the IoT smartphones (Stojkoska and Trivodaliev, 2017). The play a fundamental role if not the main role within this network.

There are many ways to define the IoT, several popular definitions are:

- “systems that (1) contain ubiquitous “everyday” objects that are accessible through the Internet and equipped with sensing, storing, and processing capabilities that allow these objects to understand their environments; (2) contain identifying and networking capabilities that allow them to communicate information about themselves; (3) involve object-object, object-person, and person-person communication; and (4) make autonomous decisions” (Van Deursen and Mossberger, 2018).
- ‘‘a dynamic global network infrastructure with self- configuring capabilities based on standard and interoperable communication protocols where physical and virtual ’Things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network” (Van Kranenburg , 2008).
- “Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts” (INFSO, 2008).

The IoT is proliferating across all sectors, creating opportunities and becoming a competitive marketplace weapon as the focus of primary benefits, shifts from both internal and external improvements of the worldwide industries (Gartner, 2016). Sectors benefitted from the IoT are: transportation, smart city, smart domotics, smart health, e-governance, assisted living, e-education, retail, logistics, agriculture, automation, industrial manufacturing, process management, among others (Gubbi*, et al*., 2013) and (Miorandi *et al*., 2012).

In 2011 Cisco predicted that 50 billion of Things would be connected to the Internet by 2020 (Evans, 2011). On the other hand, more recent investigations show that 25 billion devices will be connected to the internet by 2020 and those connections aim at facilitating the process of autonomous intelligent decision making (Gartner, 2014). No matter which prediction is right the main highlight is that smart things will be several times more than the estimated world population.

Lopez *et al*. (2017) established three main components required for the IoT namely Smart things, network infrastructure and backend servers (see Figure 2.2). This simplified architecture describes the essence behind the paradigm of the IoT.

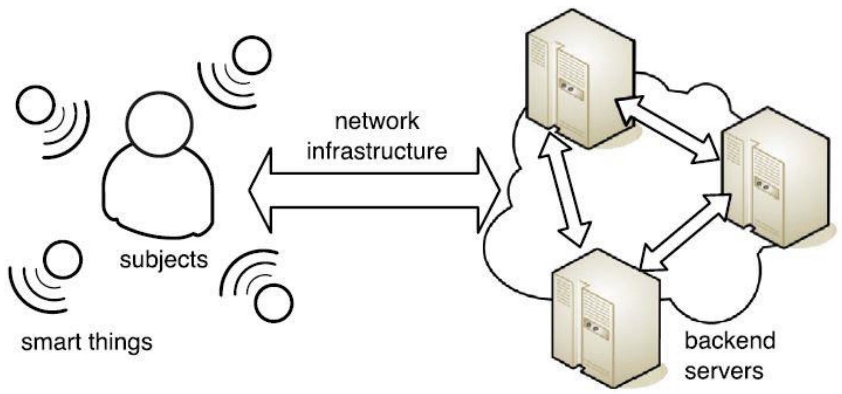

Figure 2.2: Simplified structure of IoT
Adapted from Lopez et al. (2017)

There is a broad range for the objects or "things" in the IoT, some of these objects can get different names in the literature, such as smart devices, mobile devices, smart things or smart objects. Smart devices are considered objects capable of communication and computation which range from simple sensor nodes to home appliances and smartphones (Stojkoska and Trivodaliev, 2017). This author also considers smart devices as the objects present in the network of the IoT.

The devices in the IoT should have the capability to dynamically adapt to the changing contexts and take actions based on their operating conditions; they should be self-configuring and interoperable, having unique identities and being able to communicate and exchange data with other devices and systems (Ray, 2016). Therefore, smart device should be context-aware and have network connectivity.

2.4.2 Related technologies to the IoT

Elazhary (2019) mentions the main technologies related to the IoT. Figure 2.3 shows these technologies in chronological order, starting with wireless sensor networks in the 1950s, followed by Ubiquitous Computing in 1991, pervasive computing in the 1990s, 5G cellular networks in 2008 and the Internet of Nano Things (IoNT) in 2010. This collection is debateable though because it does not include technologies as RFIDs. Nevertheless, Elazhary (2019) justifies this selection of technologies by categorising RFIDs as building block of the IoT.

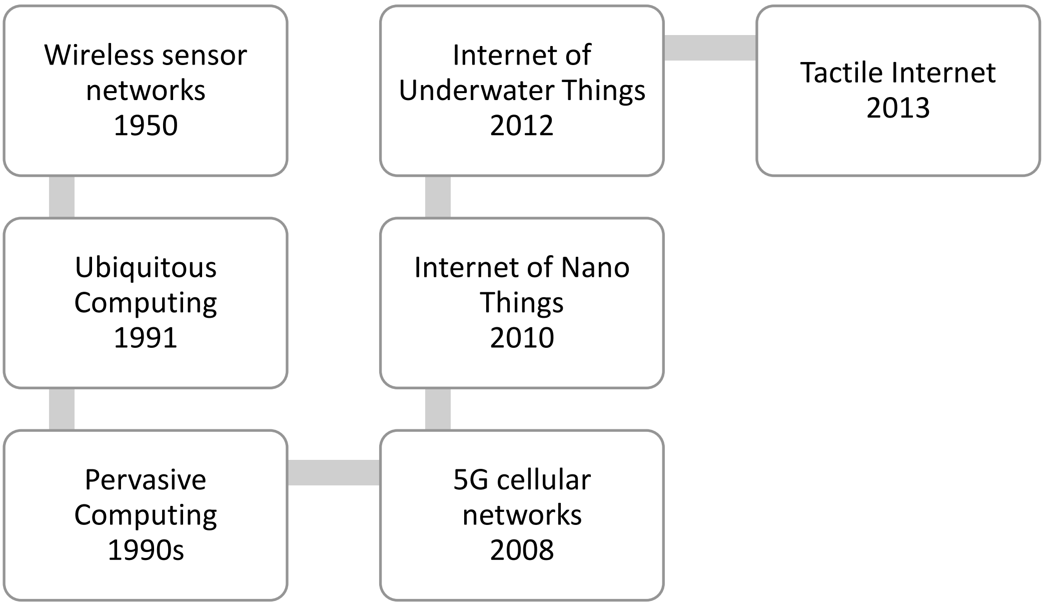

Figure 2.3: Technologies related to the IoT ordered chronographically

Adapted from Elazhary (2019)

Wireless Sensor Networks (WSNs) are formed of interconnected sensors which are equipped with a processor and flash memory and can be interfaced to a computer via a gateway (Kocakulak and Butun, 2017). The first WSN was the Sound Surveillance System (SOSUS) (Kocakulak and Butun, 2017) developed in the 1950s. It was an underwater surveillance network of submerged hydrophones (noise sensors) scattered in the Atlantic and Pacific oceans by the United States military to detect Soviet submarines. Terrestrial WSNs were proposed later in the 1980s.

The term ubiquitous computing was coined in 1991 by Mark Weiser (Weiser, 2002). He described a set of computing devices connected through a network and capable of communicating with each other such that they become part of our daily life. In the mid 1990's, IBM started research on mobile and pervasive computing to develop imbedded computers connected to mobile devices (Want, 2010). According to Mark (1999) pervasive computing to refers to computation embedded in things, such that it becomes a part of the environment causing most human interactions with them to be implicit.

The fifth Generation (5G) cellular network was proposed in 2008 in a cooperation between the National Aeronautics and Space Administration (NASA) AND Machine-to-Machine intelligence (M2Mi) corporation (Elazhary, 2018). The goal of 5G network is to enable a higher speed and M2M communication (Akyildiz *et al*., 2016).

Another related technology is the IoNT, proposed in 2010 by Akyildiz and Jornet (Akyildiz and Jornet, 2010). In this paradigm, Nano sensors are embedded in objects for fetching data from hard to reach areas such as human bodies. The Internet of Underwater Things (IoUT) was first discussed in 2012 by Mari Domingo (Domingo, 2012). It consists of a network of Internet-enabled things underneath the oceans and seas that cover about 71% of the earth's surface as a counterpart of the terrestrial IoT including Underwater Wireless Sensor Networks (UWSNs) (Kao *et al*., 2017). There are many differences between the IoT and the IoUT, such as the means of communication, tracking, and localisation techniques (Domingo, 2012).

Tactile Internet was first utilised in 2013 by Gerhard Fettweis (Fettweis, 2014). It encompasses an evolution of the Internet in terms of speed and latency. According to Fettweis (2014) "the latency of communication systems becomes low enough to enable a round-trip delay from through the network back to terminals of approximately 1ms". This means that tactile Internet enables a natural tactile and haptic sensation for the users. Tactile Internet is envisioned as a technology which will be empowered by 5G. On the other hand, the IoT is envisioned as one of the technologies behind 5G.

2.4.3 Building blocks of the IoT

The main building blocks or enabling technologies of smart devices have been studied by Elazhary (2018). Figure 2.4 presents the following technologies as foundational for IoT: Sensors, actuators, Energy Harvesting Active Networked Tags (EnHANTs), RFID, Internet of Nano Things (IoNT), short-range wireless devices and Wireless Sensor Networks (WSNs).

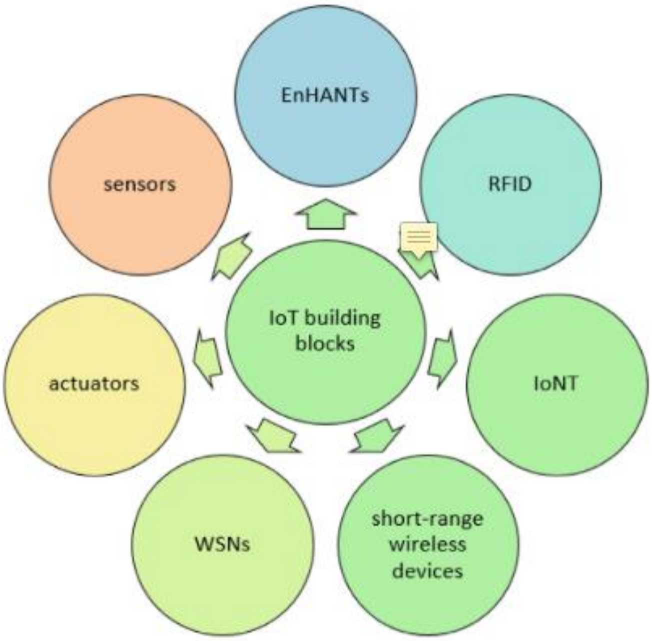

Figure 2.4: Building blocks of the IoT
Adapted from Elazhary (2018)

Sensors and actuators are a fundamental part of the IoT, in addition, WSN are considered to be promising technologies for the implementation of the IoT (Kokakulak and Butun, 2017). One research direction focuses devices that would be embedded in or attached to things in the IoT rendering them smart. In fact, according to Atzori *et al.* (2010) various researchers consider RFIDs as key building blocks of the IoT devices. According to Elazhary (2018) a RFID system contains a several tags and one or more readers. Each tag has a unique identifier and the reader is used for identifying tagged things in the neighbourhood by sending a query to corresponding tags regardless of being out of the line of sight. Tags respond by sending their IDs. Some research areas are concerned with the studies of RFID tag identification (Zhang *et al.*, 2018).

2.4.4 Intersection between Mobile and Cloud computing

The IoT is an emerging research area with many researchers envisioning that IoT computing will be one of the dominant paradigms in the near future (Elazhary, 2019). Figure 2.5 shows the intersection of the IoT, CC and MC and its numerous computing paradigms such as Mobile Cloud Computing (MCC), Mobile IoT computing, IoT Cloud Computing, and Mobile IoT Cloud Computing. Section 2.6 discusses this topic further.

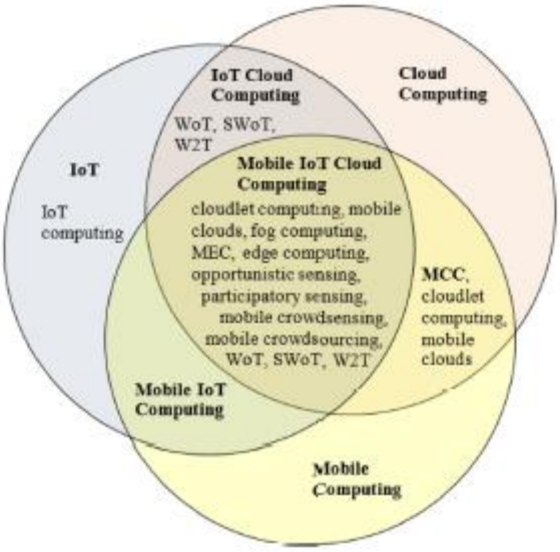

Figure 2.5: Intersecting areas of research and their relationships with various emerging computing paradigms Adapted from (Elazhary, 2019)

2.4.5 Smart homes

A home is considered smart when the user assembles a collection of smart devices under one roof and enable them to connect to a network and communicate with one another. The term home automation is also used because the smart devices work together to automate tasks and home operation (Miller, 2015). Smart homes offer users the ability to control everything in their home, as well as the ability to automate most household's chores.

There is a variety of levels of “smartification” for smart homes, that goes from adopting basic communications to task automation. (Miller, 2015) defines six steps towards home automation namely, adoption of basic communications, simple commands over the home, automating basic functions, tracking and taking action, prompting activities, and automating tasks. This study summarises these steps into four steps to make a home Smart.

2.4.5.1 Step 1: Automation of basic functions

The first step towards the smartification of a home is to automate basic functions, that is to give way to automatic controls such as room temperature, activating or deactivating the alarm system, running sprinkler system based on a specific program, etc (Miller, 2015).

2.4.5.2 Step 2: Tracking and response

The second step towards home automation is to adopt sensor technology into the home so the users can track their own behaviour to determine activity patterns, sleep patterns, or even health status. This step converts the home into a giant monitoring system. At this point the home starts generating large amount of data which is handled by programmed algorithms or basic artificial intelligence to make decisions based on the users’ behaviour (Miller, 2015).

2.4.5.3 Step 3: Prompting activities

The next step for a smart home which is already monitoring its users, is activities suggestion. Smart homes are able to remind activities to their uses based on the collected data from the users (Miller, 2015). At this point homes stop being reactionary, and predictive thus they can be considered “Smart”. Behind activity suggestion there must be a relevant data processing happening to the data collected from the users. Based on this data the home's big data algorithms can predict user behaviours or future need of information.

2.4.5.4 Step 4: Automation of tasks

Automating major tasks in the home, such as reorder medications, prepare grocery lists, or run the vacuum cleaner, can save plenty of time. Smart homes, learn and adapt so they are able to schedule household's task on their own. The automation of tasks on this level considers the data gathered through sensors and the analysis performed on such data.

2.4.6 Smart cities

A city can be defined as a large human settlement (Kuper, 2013 and Goodall, 1987). Cities generally have extensive systems for housing, transportation, sanitation, utilities, land use, and communication. Nowadays over half of the world population is said to live in cities. Present-day cities usually form the core of larger metropolitan and urban areas, creating numerous commuters traveling towards city centres for employment, entertainment, and edification.

The amount of people living in cities has increased enormously in the last decades. In the world there are over one thousand cities with more than 500,000 inhabitants. By the year 2017, there were thirty-seven cities reported as mega cities, these are cities with a population bigger than ten million inhabitants. The biggest megacity on the planet is Tokyo-Yokohama in Japan with 37.9 million people (Demographia, 2017). Asia alone has the eight biggest megacities in the world (See Table 2.1).

Table 2.1: Top 10 biggest megacities of the planet
Adapted from demographia (2017)

Country	City	Population Estimate
Japan	Tokyo-Yokohama	37,900,000
Indonesia	Jakarta	31,760,000
India	Delhi, DL – UP - HR	26,495,000
Philippines	Manila	24,245,000
South Korea	Seoul-Incheon	24,105,000
Pakistan	Karachi	23,545,000
China	Shanghai, SHG-JS-ZJ	23,390,000
India	Mumbai, MH	22,885,000
United States	New York, NY-NJ-CT	21,445,000
Brazil	Sao Paulo	20,850,000

Within the context of the United Kingdom, there is London. This city counts with an international population demographics and plays an important role within the global economic. It belongs to the group of megacities with a population of 10.5 million by 2017 (Demographia, 2017). London is the UK's only megacity by 2017, the second largest city is Manchester with a population of 2.85 million, this scenario could be either good or bad depending on the whether megacities are considered as a positive or negative thing for the agenda on sustainable development. By attempting to correlate "countries with the highest number of megacities" with the "Yale environmental performance index" it can be inferred that there is no correlation between countries with high percentage of population living in megacities and environmental sustainability. Table 2.2 shows all the countries with megacities by 2017. China, India and Japan have six, five and three megacities respectively. Their environmental index does not change accordingly with their number of megacities or either with the percentage of population in megacities.

Table 2.2: Statistics of countries with megacities by 2017

Adapted from Demographia (2017) and University of Yale's Environmental index (University of Yale, 2016)

Country	No. of Megacities	Population of megacities	Population of country	% of population in MC	Environmental performance index - Yale
China	6	99,950,000	1,379,000,000	7.2%	43.00
India	5	85,130,000	1,324,000,000	6.4%	31.23
Japan	3	65,045,000	127,000,000	51.2%	72.35
Pakistan	2	34,210,000	193,200,000	17.7%	34.58
Brazil	2	32,750,000	207,700,000	15.8%	52.97
United States	2	36,945,000	323,100,000	11.4%	67.52
South Korea	1	24,105,000	51,250,000	47.0%	63.79
Peru	1	11,150,000	31,770,000	35.1%	45.05
Argentina	1	15,355,000	43,850,000	35.0%	49.55
Philippines	1	24,245,000	103,300,000	23.5%	44.02
Thailand	1	15,645,000	68,860,000	22.7%	52.83
Turkey	1	13,755,000	79,510,000	17.3%	54.91
Iran	1	13,805,000	80,280,000	17.2%	51.08
Egypt	1	16,225,000	95,690,000	17.0%	61.11
France	1	10,950,000	66,900,000	16.4%	71.05
Mexico	1	20,400,000	27,500,000	16.0%	55.03
United Kingdom	1	10,470,000	65,640,000	16.0%	77.35
Congo	1	11,855,000	78,740,000	15.1%	39.44
Indonesia	1	31,760,000	261,100,000	12.2%	44.36
Russia	1	16,710,000	144,300,000	11.6%	53.45
Viet Nam	1	10,380,000	92,700,000	11.2%	38.17
Bangladesh	1	16,820,000	163,000,000	10.3%	25.61
Nigeria	1	13,360,000	186,000,000	7.2%	39.20

The constant growth of cities around the world entails new challenges related to finance and infrastructure. The government of the UK has established the main challenges faced by cities and the need for smarter approaches. These challenges are: Economic restructuring; pressure on housing and transport; concerns about climate change and carbon emissions; paradigm shift of consumer services towards online retail; burden on adult social care due to ageing population (UK Department for Business Innovation & Skills, 2013).

According to UK Department for Business Innovation & Skills (2013) the scale of these challenges is forcing cities to transform their strategies and adopt new techniques which integrates information, such as:

- Outsourcing services using outcomes-based contracts;
- Service integration, both back office and increasingly front-line services;
- Online service delivery;
- Releasing data to enable citizens to make informed decisions and development of new services;
- Reducing demand on services.

With the inclusion of these new techniques comes the concept of Smart city. Smart city can be initially defined as:

“A well defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well being, inclusion and participation, environmental quality, intelligent development; it is governed by a well defined pool of subjects, able to state the rules and policy for the city government and development.” (Dameri, 2013)

Even though several concepts for smart city can be found, there is no fully established concept of Smart city, therefore, the conceptualisation of smart city varies from country to country, depending on the level of development and aspirations of the city residents. According to (UK Department for Business Innovation & Skills, 2013) there is no absolute definition of smart city, but rather a process by which cities become more liveable and resilient, hence sustainable and able to respond quicker to new challenges.

Literature suggests that a smart city uses IT to make more efficient use of physical infrastructure through artificial intelligence and data analytics to support strong and healthy economic, social and cultural development (Hollands, 2008). A smart city also engages effectively with local people in local governance, improving the collective intelligence of the city's institutions through e-governance (Komninos, 2013). Finally, a smart city adapts and innovates, and thereby responds effectively and promptly to changing circumstances by improving the intelligence of the city (Coe, 2001).

2.4.7 Industry 4.0

Industry 4.0 is a high-tech paradigm that in the eyes of many researchers represents a fourth industrial revolution, after the advent of mechanisation, electrification and computerisation (Dallasega *et al.*, 2018). This new revolution describes the increasing automation of the supply chain and digital processes, as well as the creation of digital value chains that enable communication between business partners and their products (Lasi *et al.*, 2014).

The industry 4.0 arises in a context were the construction industry faces unique challenges. First, construction projects are unique, time-limited and require a high degree of customisation (Dubois and Gadde, 2002). An important challenge of the construction industry is its fragmented supply chain, which is formed by Small and

Medium-sized Enterprises (SMEs) that require great effort to coordinate (Arayici and Goates, 2012).

Oesterreich and Teuteberg (2016) discusses the benefits that industry 4.0 can bring to the construction industry such as, reduced costs, time savings, higher building quality and improved collaboration. Reduced labour costs can be obtained through the u se of robotics and automatic workflows (Bruemmer, 2016), material costs can be achieved through automatic tracking of equipment and materials through the use of RFIDs and bar coding. The implementation of BIM can improve building quality by allowing timely discovery of potential problems through increase detail and information in the design phase (Allison, 2015). Cloud platforms can improve collaboration among companies and contribute with the project delivery time and budget (Merschbrock and Munkvold, 2015).

Just as RFIDs, sensors and actuators are founding blocks of the IoT, the same way the IoT can be considered as a founding block for the industry 4.0. Hence, this section was considered of value for establishing the context of the literature around smart devices.

2.5 Artificial intelligence and big data analytics

Artificial Intelligence (AI) is defined in the whitepaper of Tractica (Kirkpatrick and Wheelock, 2018) as:

> *"An umbrella term for multiple technologies that are designed to provide computers with human-like abilities of hearing, seeing, reasoning, and learning. These techniques, which include Machine Learning (ML), Deep Learning (DL), Computer Vision (CV), and Natural Language Processing (NLP), unmask*

hidden patterns in large data sets and then using complex algorithms, can correlate findings between seemingly unrelated variables".

This definition explains the reach and dimensions of AI. In addition, Figure 2.6 shows a diagram which explains the intersection between AI and Big Data Analytics. DL is a sub domain of ML which is a sub domain of AI. ML is utilised in Big data analytics to analyse large datasets.

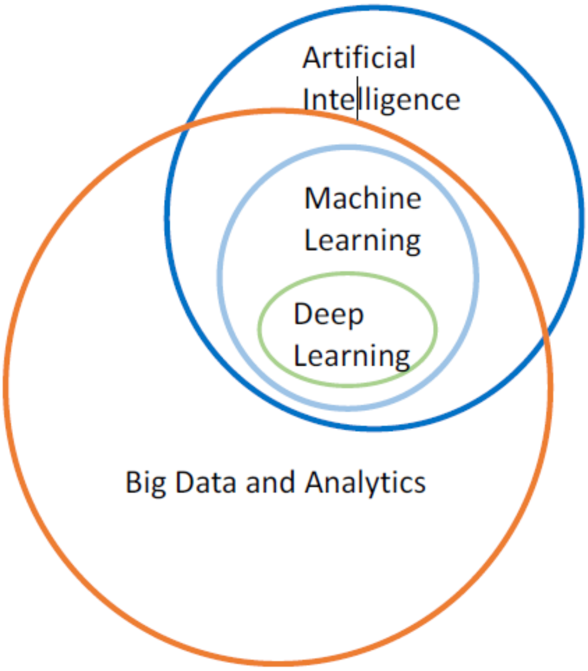

Figure 2.6: Domains of AI, ML, DL and Big data
Adapted from Kirkpatrick and Wheelock (2018)

An organisation that wishes to deploy an AI solution requires to understand its underlying technologies. ML is a type of AI that uses computerised mathematical algorithms to learn from data and build a probabilistic model for making assumptions and predictions about similar datasets. DL is a type of ML that uses the model of human neural networks to make predictions about new datasets (Tractica, 2018). NLP enables computers to understand human language as it is spoken and written and to produce human-like speech and writing. CV attempts to identify images of objects that can be seen.

AI and Big data analytics are used together as a tool for evaluating very large datasets. Big data analytics can support project managers in more effective decision making through increased access to information (McMalcom, 2015). Improving work safety on-site in construction projects, given the industry's hazardous work environment and high rate of work injuries and accidents (Chun, Heng and Skitmore, 2012).

2.6 Mobile and Cloud computing

The concept of CC was first introduced in 2004 (Vouk, 2008). It has been defined by practitioners in commercial and academic spheres in different perspectives and visions. More than 20 definitions have been found by Vaquero et al. (2009) about CC. The most widely recognised definition of CC is provided by the National Institute of Standards and Technology (Mell and Grance, 2011). According to this definition of CC:

> *"Cloud computing is a model enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storages, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."*

CC makes applications available remotely and would be an advantage in construction management. This would allow the staff to work from any place without being tied to any specific location (Rountree and Castrillo, 2013). Cloud computing also provides a healthy working environment and contributes to energy sustainability by cutting down the use of multiple servers and computers by using virtual computing technology. This would reduce the carbon footprint, also cut down the floor space needed for multiple server racks (Menken , 2012). In addition to these positive features, there is a set of potential risks in implementing CC. Such risks include but are not limited to data security, integration with legacy systems and inability to restore and backup data (Jansen, 2011). Any industry attempting to implement CC should consider both benefits and risk in its implementation.

The construction sector is a fragmented industry, where many stakeholders and parties need to work together to deliver a project successfully. This industry has always had challenges like finance, reputation and productivity; current trends in the industry attempt to embed sustainability into projects and implement relative new technologies like BIM, which transforms the typical building design cycle. Furthermore, new management tools and techniques have been developed which enhance productivity and cross-communication.

MCC comes from the integration of CC in handheld devices which provides mobility and ubiquitous data access as main features. According to (Abolfazli *et al.*, 2014) the Infrastructure of MCC suggests an objective and subjective perspective for addressing an MCC environment, which in terms of execution of cloud-based mobile applications present mostly benefits since they enable users to execute ubiquitously high-performance operations in mobile devices.

According to NIST, the cloud computing model comprises five essential characteristics, three service models and four deployment models (Mell and Grance, 2011)**.**

The characteristics found in the cloud computing model are on-demand self-service, resource pooling, broad network access, measured service and rapid elasticity (Mell and Grance, 2011). On-demand service denotes the unilateral provisioning of resources without human interaction with the provider while resource pooling refers to the aggregation of resources such as storage, bandwidth, etc. Broad network access denotes services being delivered over a network. Measured service is the automatic control and optimization of resources through pay-per-use metering capabilities. Finally, rapid elasticity accounts for resources being dynamically scaled up and down with demand (Brender and Markov, 2013).

There are different types of clouds, each with its own advantages and disadvantages. According to NIST in terms of deployments, there are private clouds, public clouds, community clouds and hybrid clouds (Mell and Grance, 2011). In public clouds service providers offer their resources as services to the public. On the other hand, in private clouds, the cloud infrastructure is provided only for the use of a single organization, thus giving the organization more control over security and transparency. Community clouds provide cloud infrastructure to several organizations with similar security concerns and compliance requirements (Carroll *et al.*, 2011). Hybrid clouds are a combination of several cloud types, such as public, private or community (Brender and Markov, 2013).

When migrating to a cloud computing system, organisations can choose the right combination of CC services models according to their needs. The three CC service models are Software as a Service (Saas), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) Figure 2.7 shows a current example of services offered within each model (Zhang *et al.*, 2010).

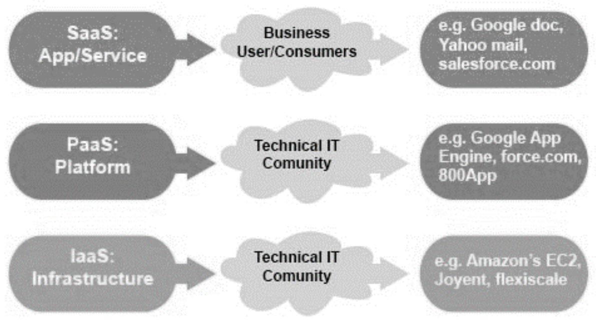

Figure 2.7: Service models in cloud computing

IaaS refers to the on-demand provisioning of infrastructural resources, such as processing, storage and networks. Examples of this type of cloud solution include Amazon's Elastic Compute Cloud (EC2), Joyent and GoGrid's (Sultan, 2011). PaaS refers to providing platform layer resources such as operating system support and software development frameworks, thus offering an operating platform that enables the disposition of existing applications that use programming tools from the provider. Products in this group include Microsoft Azure, Google App Engine and Amazon Web services (Sultan, 2011). PaaS provider can run its cloud on top of an IaaS provider's cloud, however, according to (Zhang *et al.*, 2010) in current practice, IaaS and PaaS providers are often parts of the same organization (e.g., Salesforce and Google). For this reason, the term infrastructure providers are utilized when referring to PaaS and IaaS providers (see Figure 2.8).

On top of PaaS and IaaS, there is SaaS, which runs on cloud infrastructure and provides a range of applications, such as spreadsheets, word processing, HR management, customer relationship management (CRM), enterprise resource planning (ERP) systems, etc. With a limited control over the applications' configuration settings SaaS has the lowest degree of customization, nevertheless, users can also customize the products by developing specific components based on Application Program Interfaces (APIs) made available by cloud providers (Sultan, 2010).

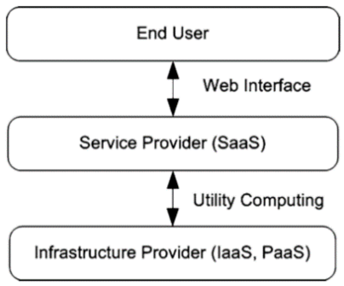

Figure 2.8: Service models diagram
Adapted from Zhang et al. (2010)

2.6.1 Potential benefits of implementing cloud computing in construction management

(Cheng and Kumar, 2012) reviewed previous studies regarding the perceived benefits of the cloud computing model according to the IT Cloud services Survey conducted by the International Data Corporation. Subsequently, the nature of the construction industry and the cloud computing model was reviewed, suggesting four major benefits of CC for construction collaboration and management. Such improvements are in cost, mobility, flexibility, and maintenance and updating.

2.6.1.1.1 Cost reduction

The conventional way of IT delivery presents a major difference with cloud computing model mainly because of the utility-based pricing model of such model. Most AEC companies are SMEs with small employees and little budget, these features are a crucial barrier of IT adoption in the AEC industry. CC present itself as a solution that seems to address this vital issue for the construction industry (Cheng and Kumar , 2012).

Currently, cloud computer users pay the service providers based on a month or annual subscription, also depending on the amount of IT resources and time that are used. Traditionally, companies make payment at the time when they purchase software and hardware systems. The initial investment is redeem eventually depending on the designated usage duration of the systems. Enabling cloud users to pay monthly or for their usage, allow them to switch to cheaper options whenever available or required. The user can also terminate the contract earlier with the cloud service providers if the project finishes in a shorter timeframe (Cheng and Kumar, 2012).

2.6.1.1.2 System mobility

In a cloud computing environment, systems and programs operate on the clouds. That means end users can access the same information from different locations and run computationally demanding applications such as structural analysis only by using a web-enabled device, e.g. desktop computers or smart phones.

2.6.1.1.3 System flexibility

The level of IT that a project needs varies throughout its lifecycle, hence the convenience of cloud-based resources. These can be flexibly deployed and terminated, as well as scaled up and down. Consequently, IT cost changes to a variable cost rather than a fixed cost.

2.6.1.1.4 System maintenance

IaaS and PaaS providers continuously maintain their systems and deliver IT resources such as CPUs, memory and operating systems as individual services. As a result, this avoids the disposal of companies' obsolete computers and continuous installation of patches for operating systems.

2.6.2 Potential risks in the adoption of Cloud Computing

CC presents significant risks and challenges. According to a survey of nearly 1800 US businesses and IT professionals by the Information Systems Audit and Control Association (ISACA, 2010), 45% consider the risks of CC as outweighing the benefits. (Brender and Markov, 2013) establishes the main topics of concern regarding the adoption of CC from a management point of view as follow: Information security; Privileged user access; regulatory compliance and data location; investigative support; availability and disaster recovery; and provider lock-in and long-term viability.

2.6.2.1.1 Information security

Information security is one of the major concerns regarding the adoption of cloud services, the technology's presence on the internet and the substantial concentration of data present an attractive target for hackers (European Network and Information Security Agency, 2009). According to (Carroll, Van Der Merwe and Kotze, 2011), information security is rated as a top threat in interviews with South African participants. In addition, (Sultan, 2011) cites a survey carried out by the International Data Corporation (IDC) where around 75% of respondents said they were concern about security.

2.6.2.1.2 Privileged user access

Another important risk is privileged user access, this denotes the existing risk of a malicious insider who may cause brand damage, and financial and productivity losses to a cloud customer (Hubbard and Sutton, 2010). For a better understanding, it is necessary to remember that the processing of sensitive data outside the premises of a company bypasses the security controls that an in-house IT department employs. Hence a good practice for customers is to procure information on the hiring and oversight of privileged cloud administrators (Heiser and Nicolett, 2008). A solution established for this concern is the use of the least privilege principle, which proposes granting to individuals or processes the minimum privileges and resources for the minimum period of time required to complete a task (CSA, 2011).

2.6.2.1.3 Regulatory compliance

Regulatory audit compliance is an important concern among cloud subcontractors. According to (Heiser and Nicolett, 2008), traditional cloud providers have to submit to security certifications and external audit and provide customers with information about the security controls that have been evaluated. With regards to the privacy regulations in different jurisdictions, data location is a big concern among companies subcontracting cloud services. One example is the data held in US-based data centres, which may be accessed by the US government as provided by the Patriot Act.

2.6.2.1.4 Data location

EU governments have privacy regulations that prohibit the release of certain data outside of the EU. Consequently, Companies like Amazon and Microsoft allow their customers to choose the physical location of the data (e.g. EU or US).

2.6.2.1.5 Availability and disaster recovery

Availability of cloud services is an important point of concern for businesses, especially for critical business processes. (Heiser and Nicolett, 2008) suggest that any enterprise procuring outsourcing critical business processes to the cloud should establish, together with the provider a Service Level Agreement (SLA) for the availability of service for critical business processes. A similar issue is disaster recovery. According to (Carroll *et al.*, 2011) it is considered as an area of critical importance and ranks second after information security by 66.7% of the votes. In addition, (Prakash, 2011) establishes the importance for a business to require information on what happens to their data in case of disaster and how long the recovery process could last.

2.6.2.1.6 Additional Risks and challenges

After analysing a study conducted by consulting firm Cambridge Technology Partners about Swiss businesses' engagement in CC, (Brender and Markov, 2013) obtained several legal, technical and operational risks or threats in migrating to a cloud service. The original study submitted five reports analysing the risks and challenges and proposing mitigation practices in the adoption of public cloud services by five companies based in Switzerland. Two of these companies can be considered as small and medium enterprises (SMEs) and the other three as economically significant enterprises.

The risks summarised by (Brender and Markov, 2013) are: Teething problems, application performance on the cloud, loss of governance, determination of the competent authorities in case of conflict, cost, economic denial of service, data segregation, data destruction, data traceability, security during data transportation, security of financial transactions and physical security and natural disasters.

2.6.3 Mobile Cloud Computing

MCC employs both the storage services and application processing services of computational clouds to enable off-device storage and compute-intensive applications on mobile devices (Ahmed*, et al*., 2015). According to (Abolfazli*, et al*., 2014), MCC focuses on alleviating resource limitations in mobile devices by implementing a variety of augmentation strategies; such as storage augmentation, screen augmentation, application processing augmentation and energy augmentation. (Ahmed*, et al*., 2015) establish MCC as a computing model which reduces the development and execution cost of mobile applications while at the same time extends the widespread services and resources of computational clouds for mitigating resource limitations in mobile devices. Hence enabling the mobile user to acquire new technology conveniently on demand basis.

2.6.3.1 Infrastructure and management of mobile cloud computing

The augmentation of computing resources of mobile devices is possible thanks to MCC. Several infrastructures need to work in the same environment in order to enable MCC; namely wireless infrastructure, backhaul, backbone, provider infrastructure and cloud infrastructure (Marotta*, et al*., 2015). This infrastructure can be better appreciated in Figure 2.9.

As can be seen in Figure 2.9 in a mobile cloud computing environment the end-user, establishes communication with a Base station or Access point though a mobile device, requesting a resource augmentation from the cloud. After reaching the Base station, the request is forwarded through the Backhaul to an Internet Service Provider

(ISP). The backbone routes the request along one or several ISPs. Once the request reaches the destination ISP, it accesses the Provider infrastructure, where the target cloud receives the request and allocates resources inside the Cloud Infrastructure. Inside the cloud infrastructure, virtual nodes communicate with one another through virtual links; such links are an abstraction of the real network links with specific features, such as routing protocol, capacity and virtual node endpoints. Finally, the Cloud provides the requested resources, replying to the Mobile Device across the five infrastructures (Marotta*, et al.*, 2015).

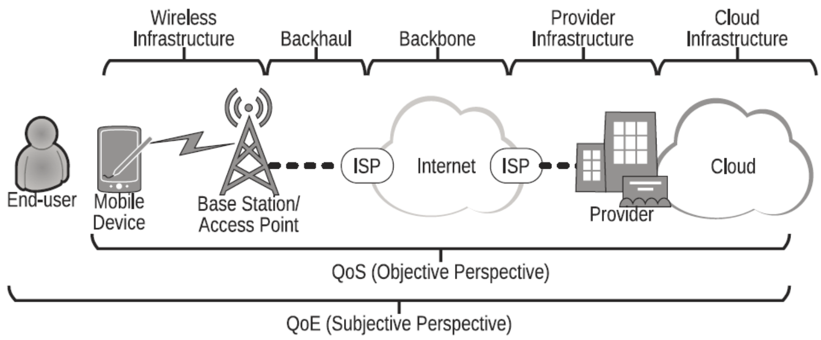

Figure 2.9: Mobile cloud computing environment

Adapted from Marotta et al. (2015)

The Quality of Service (QoS) provides an objective view about the quality of network, considering parameters like throughput, delay and jitter; QoS encompasses every element of the MCC infrastructure with the exception of the end-user (Abolfazli*, et al*., 2014). On the other hand, the Quality of Experience (QoE) provides a subjective view about the quality of network, with parameters like satisfaction level with application navigation, cloud ubiquity and response time (Rengaraju*, et al.*, 2012). Both QoS and QoE parameters are important for a MCC service. Usually, administrators focus their attention on QoS parameters whereas End-users pay more attention to QoE parameters.

In terms of management (Boutaba and Polyrakis, 2001) mapped five functional areas into key requirements for any MCC management systems, namely Fault, Configuration, Performance, Accounting and Security. (Marotta*, et al.*, 2015) considers that the scalability of the MCC environment would lead to having other requirements. However the requirements established by (Boutaba and Polyrakis, 2001) are broader, thus encompassing other requirements. These requirements are better explained in Table 2.3.

Marotta *et al*. (2015) establishes two management entities in the network management research field, namely agents and managers. The agent is a software module placed inside an infrastructure component and is responsible for monitoring local parameters, such as maximum transmission unit and available memory. The manager, on the other hand, is a role assumed by a network node, e.g., routers or computers, and is responsible for retrieving information from agents and managing a network slice or domain.

Table 2.3: MCC management requirements

Adapted from Marotta et al. (2015)

Requirement	MCC environment
Fault	The management system must be aware of the five infrastructure faults, to avoid QoS and QoE degradation
Configuration	The management system must reconfigure the five infrastructures to achieve correctness and autonomy based on QoS and QoE.
Accounting	The management system must monitor and measure the usage of the five infrastructure through QoS and QoE for billing correctness and auditing purposes.
Performance	The management system must support a large number of mobile services performing asynchronous communications to avoid compromising the proper operation of the MCC environment
Security	The management system must authenticate, Authorize, and Account (AAA), End-users actions inside the MCC environment, avoiding impersonation attacks as well as providing a stronger auditing.

2.6.3.2 Execution of cloud-based mobile applications

Cloud-based mobile applications run both on the cloud and mobile devices, consisting of two types of components: transferable and non-transferable. Transferable components are compute-intensive tasks and do not interact with the mobile hardware. Instead, they are transferred to the cloud. Non-transferable components are implemented in the mobile devices and are designed for especial functionalities; such as user interface and hardware access (Cuervo *et al.*, 2010).

In MCC (Ahmed*, et al*., 2015) defines three states for cloud-based application; such as running state, paused state and terminated state. The execution of a mobile application starts as soon as the user taps the application icon. After this, the application enters the running state where different tasks can be performed. When the migration into the cloud is required the application to enter a paused state and all the running states are saved and migrated to the cloud server where the application is resumed and reconfigured using the saved states. Finally, after finishing the execution on the cloud server, the results are pushed back to the mobile device, where the application resumes its execution, where on completion the application stops and enters into the terminated state.

In context of optimal application execution, various metrics are defined by (Ahmed*, et al*., 2015) for optimal application migration of mobile applications. These metrics can be classified into five different areas, namely network, application type, mobile device, cost and user preferences.

Network related parameters are wireless link quality, latency, security, available bandwidth, network latency and network cost. To attain the optimal execution of mobile cloud applications, it is recommended to select a network with low latency, available bandwidth and better wireless link quality, thus reducing execution time.

The application type plays an important role in the adoption of a cloud integration. The characteristics of mobile applications vary from application to application. According to (Zhang and Figueiredo, 2006), mobile applications can be classified as CPU-intensive, memory-intensive, and input/output-intensive. In addition, (Nazir, Ma and Seneviratne, 2009), (Cano and Domenech-Asensi, 2011) and (Ballagas *et al.*, 2007) classify mobile applications as delay-sensitive, security-intensive and network-intensive respectively. When considering off-loading the processing tasks of an application to the cloud, the best candidates are memory and CPU-intensive applications; whereas input, network and security-intensive application will show more constraints to run in a remote cloud.

Important metrics to consider related to mobile devices are CPU speed, memory, storage, battery, wireless access technologies, and number of interfaces. These parameters are used to build the processing load, which is used to determine if an application process may not have a sufficient number of CPU cycles for its execution. Subsequently, such application requires migration to remote cloud server for smooth execution (Lenders, Wagner and May, 2006).

The parameters related to cost are mainly the monetary cost of wireless networks and the cloud. Usually users can use WiFi for application offloading, nevertheless whenever WiFi is not available, a mobile user can switch to the internet service provided by the network.

In terms of user preferences there are three parameters to consider for running an application in dynamics wireless environment with a variety of access technologies, namely Quality of Services, cost and security.

2.7 BIM and Smart devices

BIM creates and manage information in a construction project during a projects lifecycle (NBS, 2016). The implementation of BIM in construction projects can increase collaboration within project teams, improved profitability, reduced costs, better time management and improved customer/client relationships (Chong, Wong and Wang, 2014).

Smart devices are used in the construction phase of a project to add mobility to the workforce, therefore, users can access and edit BIM data from a tablet or smartphone anywhere in the project. Therefore, smart devices can be considered as a BIM enabling technology.

The relationship between smart devices and BIM justified the inclusion of BIM in the literature review. Therefore, this section attempts describes key aspects of the BIM paradigm such as the most common BIM maturity models and challenges and drivers in BIM implementation.

2.7.1 BIM Maturity

Since BIM is a process for information management, its maturity in an industry is observed and assessed. Two maturity models have been used to discuss BIM maturity. First, Bew-Richards BIM maturity model (Bew and Richards, 2008). This model shown in Figure 2.10 is the most widely used maturity model to discuss the BIM maturity in an industry or an organisation.

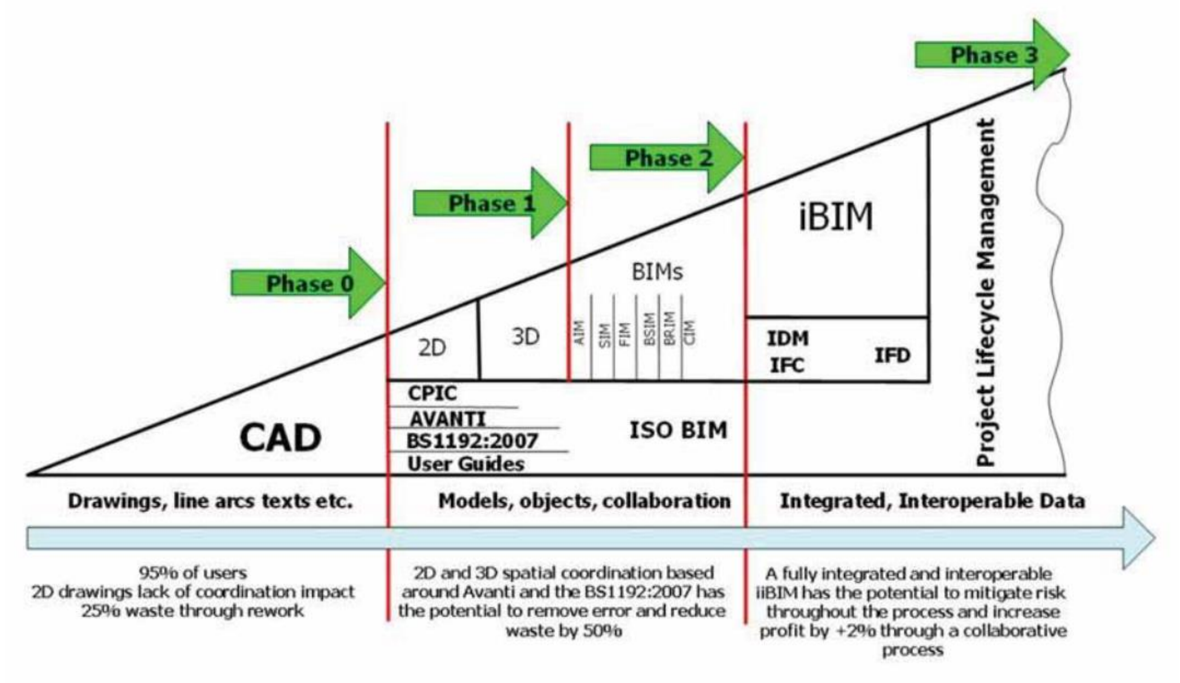

Figure 2.10: Bew-Richards BIM maturity model

Adapted from Bew and Richards (2008)

Bew-Richards model identifies basic CAD (Computer Aided Draughting) as "Phase 0" or "no BIM maturity". At this stage, CAD is utilised to replace conventional drawing board, representing information using lines and curves on a 2D plane. In these drawings no intelligence such as layering, and blocks are expected. The model considers use of intelligence on basic CAD usage as the entry into early BIM maturity phase. A BIM infant industry will find itself in Phase 0, or at most at the entry of Phase 1. Phase 1 starts with introduction and application of best practices and supported standards. This stage usually comprises a mixture of 2D CAD for drafting of documentation, 3D CAD for concept work and electronic sharing o data carried out from a Common Data Environment (CDE). Level 2 BIM is about collaborative working, and information exchange among project participants, also the project parties must be capable of producing common files formats such as Industry Foundation Class (IFC) or COBie (Construction Operations Building Information Exchange).

Bew-Richards model is the most popular around BIM implementations, especially in the UK. It was developed particularly to implement BIM in the UK, this can be seen in the association of this model with many British standards such as: BS 1192:2007, BS 1192-3:2014, BS 8536-1:2015 or BS 8536-2:2016. However, when discussing an international BIM implementation this model lacks behind in specifying the full workflow of the implementation of BIM. Another BIM maturity model was presented by Succar (2009), which goes from a Pre-BIM implementation stage towards a full Integrated Project Delivery. Figure 2.11 shows the linear BIM maturity stages of Succar (2009).

Figure 2.11: Linear BIM maturity stages
Adapted from Succar (2009)

According to Succar (2009) on BIM Stage1 BIM implementation is initiated through a deployment of an ‘object-based 3D parametric software’ such as Revit®, ArchiCAD®, Digital Project® or Tekla®. At this stage, users focus on generating single-disciplinary models oriented on one of the project’s lifecycle stages (design, construction or operation). On BIM Stage 2, distinct teams engage in a model-based collaboration with other disciplinary teams. On BIM Stage 3 the project teams create and maintain semantically-rich integrated models across project lifecycle phases. BIM Stage 3 models become interdisciplinary models which allow complex analyses at early stages of the project.

Both maturity models offer a mapping for the level of implementation of BIM. However, Succar's model is a more linear and simplistic approach, while Bew and Richards offer a more flexible and layer-based approach.

2.7.2 Challenges of BIM implementation

Challenges and drivers for BIM implementation have been evolving over time. Chen, Chang and Lin (2016) highlights a current issue with the BIM industry: Although a common BIM file format has been proposed, which is the industry foundation classes (IFC); the logic and definitions of BIMs among commercial software vary endlessly. Therefore, it results very complicatedly to maintain consistency on the exported information format and content for the IFC exported by different commercial BIM software. They may even lead to loss of important data from the BIM project, even with the same commercial BIM software. With a specific software, different versions are likely to experience compatibility issues for transferring BIM projects. Consequently, managing BIMs in many projects remains a challenge, despite the fact some BIM software vendors have developed viewers for accessing different versions of BIMs.

Some studies suggest that BIM should be incorporated with new technologies, such as cloud computing (Chong, Wong and Wang, 2014), but instead of thinking of cloud computing as a new technology to be incorporated with BIM, it should be thought of as a requirement for a fully functional BIM implementation. To obtain collaboration between project parties, it is necessary to share a BIM project and related information through the Cloud. Additionally, by implementing MCC, users can perform more intensive operations related to BIM, such as access, consult or modify properties from the project's dataset.

2.8 Augmented reality (AR)

AR represents a viable and efficient approach for combining virtual reality with the real world (Kamat*, et al*., 2010). AR augments user's perception of a real-world entity by inserting relevant digital information into the real environment. Similarly, Chi *et al*. (2013) explain AR creates an environment where computer generated information is superimposed onto the user's view of a real-world scene.

Simple AR solutions are marker based; this means that rely on markers to locate the overlay information on the screen. More robust solutions are context-aware, this means that they provide relevant information to the user based on the user's task and context.

According to Abowd *et al.* (1999) context can be defined as:

> *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."*

This definition makes it easier for an application developer to enumerate the context for a given application scenario. If a piece of information can be used to characterise the situation of a participant in an interaction, then that information is context. According to (Hong, Schmidtke and Woo, 2007) context can be classified into preliminary, integrated and final context. Preliminary context refers to raw sensor measurements, whereas integrated context encompasses inferred information from distinct sensors. Final context addresses information processed by the application, which tries to generate a higher level of understanding about the user's behaviour.

Although this categorization divides context into a three-level scheme, ultimately context derives from the device's sensors. Hence, context-aware applications try to understand what the user is doing by using information obtained from sensors.

To be more specific, Abowd *et al.* (1999) established a context-aware system as follows:

> *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."*

The application of visualisation techniques such as AR for planning, analysis, and design of Architecture, Engineering, and Construction (AEC) projects is relatively new compared to the sizeable amount of AR-related research conducted for diverse applications in fields such as manufacturing, medical operations, military, and gaming (Agarwal, 2016).

Recent investigations suggest that the implementation of AR applications in the AEC require the development of Pervasive AR solutions (Grubert *et al*., 2017). Pervasive AR is a continuous and pervasive user interface that augments the physical world with digital information registered in 3D, while being aware of and responsive to the users' context (Grubert *et al*., 2017). Moreover, Pervasive AR is the integration of context-awareness, responsiveness and continuity into traditional AR.

2.8.1 Development of context-aware augmented reality in the Construction industry

One of the first attempts to develop an AR system solution was Sketchand+. It is an experimental tool which made a first attempt to use AR in the early architectural design stages. This AR prototype utilised a scribbling interface through the metaphor of a digitizer tablet and provides a 3D sketch as a virtual response. The next generation of sketchand+ is BenchWorks, developed as an AR prototype for analysing representational design in an urban design scale, which focused on techniques and devices necessary to create 3D models for urban design. The system was designed as a workbench, which combined optical tracking with magnetic tracking. Another AR system derived from ARToolKit was developed by (Dias *et al.*, 2002), which provides a Mixed Reality system for implementing tasks in architectural design, which developed tangible interfaces using ARToolkit patterns on a paddle and gestures.

There are several noted efforts towards collaborative AR systems in design and planning. For instance, Wang and Dunston, (2009) developed an intuitive mixed environment called Mixed Reality-based collaborative virtual environment (MRCVE) to support the collaboration, design and spatial comprehension in collaborative design review sessions. The environment could be for mechanical contracting, face-to-face manner or distributed over network. Some investigations are focused on to the utilisation of AR technologies to address problems in the fields of AEC.

Table 2.4 shows various research projects oriented to provide cyber-information to field personnel through mobile devices and/or AR systems. Some of these investigations have primarily focused on using Wireless Local Area Networks (WLAN), Global Positioning Systems (GPS), or Indoor GPS for accurately positioning the user within congested construction environments. Meanwhile, others have attempted to implement AR to help with heavy equipment operations. A common conclusion of these investigations is the positive effect obtained by the integration of AR in one or several processes of the Construction industry.

Table 2.4: Compilation of some of the main AR research projects for the Construction industry

Year	Contribution	Reference
2006	Presentation of various case studies to illustrate the concept of context-aware service delivery within the Construction industry	(Anumba and Aziz)
2007	Utilisation of AR to assist in the training of operators of heavy equipment	(Wang and Dunston)
2007	Utilisation of AR to develop a cooperative reinforcing bar arrangement support system	(Yabuki and Li)
2008	Discussion of the importance of location in context-awareness. Location aware apps can utilise the knowledge of the user location to provide relevant information.	(Behzadan, *et al*)
2008	Investigation of constraints related to construction sites for the implementation of accurate calibration methods for multi-range AR systems.	(Shin, Jung and Dunston)
2009	Utilisation of AR to display 4D models used for managing construction activities	(Golparvar-Fard *et al*)
2009	Utilisation of AR to display the positioning and layout of underground infrastructure and to mitigate undesired damages.	(Schall, *et al*)
2009	Investigation of effectiveness of three wireless technologies for dynamic indoor user position tracking	(Khoury and Kamat) [a]
2009	Investigation of algorithms for identification of contextual data in location-aware applications, based on a dynamic user-viewpoint	(Khoury and Kamat)[b]

	tracking scheme in which mobile users' spatial context is defined by position and three-dimensional head orientation.	
2013	Development of low-cost mobile AR-based tool for facility managers which reduces data overload inefficiencies and enhance situation awareness	(Irizarry *et al*)
2013	Investigation of mobile AR system which enables a project's workforce to query and access 3D information on-site by utilising photographs taken from standard mobile devices. The user's location is derived from a 3D point cloud model generated from a set of pre-collected site photographs which is compared agains the users's images.	(Bae, Golparvar-Fard and White)
2015	Measured the potential used of AR in civil engineering and compared to other technologies	(Meža, Turk and Dolenc, 2015)
2016	Examined the concept of AR and its various implementations in Civil Engineering.	(Agarwal, 2016)
2017	Presented the concept of Pervasive Augmented reality.	(Grubert, *et al.*, 2017)

2.8.2 Conceptualisation of pervasive augmented reality

The first step in traditional AR is tracking and registration, which according (Chi, Kang and Wang, 2013) determines where to display digital contents. Initially, tracking and registration were performed using marker-based tracking toolkits. For designing various marker-based applications, different toolkits such as ARTag, ARToolKit and ARToolKit Plus are utilised. ARToolKit is open sourced, easy to configure, well-documented and widely used in AR applications. Also, it has less execution time than ARTag and ARToolKit Plus (Khan, Ullah and Rabbi, 2015). Nevertheless, although

ARToolKit is a simple toolkit, its users still have several problems in their attempt to achieve high quality and robust tracking of the markers.

With the rise of mobile and wearable devices, the increasing availability of geo-reference and user generated data and the accessibility of high speed; the construction industry counts with the right scenario for implementing AR technologies based on real-time data (Grubert *et al*., 2017). This enables the users of AR systems to interact with their surroundings instantaneously.

Current AR applications usually serve a single purpose and are used only for short times. Standards used in AR hardware and sofware prevent a continuous, multi-purpose usage of the interface. However recent developments on head-mounted AR products have enabled a continuous AR experience (Grubert, Kranz and Quigley, 2015; Grubert*, et al*., 2017) refers to the concept of continuity in AR experience as "pervasive augmented reality" addressing it as a continuous, omnipresent and universal augmented interface to provide information in the physical world. Furthermore, it is defined as follow:

> *"Pervasive Augmented Reality is a continuous and pervasive user interface that augments the physical world with digital information registered in 3D while being aware of and responsive to the user's context."*

Consequently, Pervasive AR derives from the addition of context awareness and continuity to typical AR.

2.8.3 Challenges for the implementation of AR in the Construction industry

2.8.3.1 Cost of AR technology

Being a relatively new concept, the initial costs of setting up an AR system in place can increase the costs of the projects (Agarwal, 2016). An increased cost would cause a negative acceptance among the decision makers of the project.

2.8.3.2 Hardware issues

The main goal of AR applications is to overlay virtual information on top of real-world objects. AR applications need to create the perception that simulates that virtual and real entities coexist in the same space with an adequate spatial alignment of real and virtual entities, without proper registration, this perception is compromised (Agarwal, 2016).

Size and weight represented another important issue to consider (Azuma *et al*., 2001). Nowadays Smart devices allow user to implement AR-based applications with mobility. Others head mounted displays like the Daqri Smart helmet and HoloLens are aiming to provide a mobile solution for the manufacturing and construction industry (Greenhalgh *et al.*, 2016).

2.8.3.3 Development of applications

The development of user-friendly applications that abide to the right paradigm of context-awareness and pervasiveness is an important barrier for implementing pervasive AR solutions. With the field of AR being very vast and diverse companies need to consider developing applications specifically for the Construction industry.

2.8.4 Drivers for the implementation of AR in the Construction industry

2.8.4.1 Error and Cost reduction

The most significant advantage that this technology provides to the user is the reduction of errors that may take place during the construction proves. By providing a virtual design on the field, it becomes easier to control the different processes and achieve a better output (Agarwal, 2016).

Since error rectification reduces, the cost of material and workforce utilised for that rectification is reduced, that helps in reducing the overall overheads of a project (Agarwal, 2016).

2.8.4.2 Continued assistance

Pervasive AR is all about continuity instead of isolated tasks, this means that all the possible applications of this technologies should be integrated into a personalised single device or system which provides continued assistance to the user (Grubert*, et al*., 2017).

2.8.5 Possible applications of pervasive AR

Based on the literature possible applications of AR include: Design, visualisation of drawings and technical information onto the jobsite, and marketing.

2.8.5.1 Design

Spatial models can help the designer identify the flaws and rectify them at the design stage itself. Also, it can contribute to create innovative designs as the architect can see the structure in real time, which can help in various advantageous changes (Agarwal, 2016).

2.8.5.2 Visualisation of drawings and technical information onto the job site

The translation of drawings into a structure is not an easy task. It involves various steps of identification of different structural elements and subsequently constructing them. Since the project is envisaged in phases, it may so happen that errors might creep in during various stages (Agarwal , 2016). The visualisation of drawings into 3D structures requires the integration of AR with other technologies such as BIM, to enable context aware solutions based on 3D information. One example is the utilisation of AR to display the positioning and layout of underground infrastructure and to mitigate undesired damages (Schall *et al*., 2009).

2.8.5.3 Marketing

Explaining a project to a person without a technical background is a problem that all projects have to face. Architectural drawings may be extraordinary, but they are still on a smaller scale and generally 2-D. Using the concept of AR, the client can be given a virtual tour of the project, with all the colours and the different views that can be observed for the project. This can lead to better marketing strategies for organizations (Agarwal, 2016).

2.9 Geographical Information Systems (GIS)

GIS is a system to capture, store, manipulate, analyse, manage and present all types of geographical data (Sweeney, 1999). A comprehensive review of the application of GIS in construction activities was performed by (Bansal, 2007), presenting solutions like: subsurface profiling, construction cost estimation and quantity take-offs, materials layout at construction site, construction site layout, real-time schedule monitoring systems, route planning and topography visualisation.

Some research projects find relevant to develop a BIM-GIS system where the benefits of both technologies are brought together into a single model, which can maximise both values. Some studies addressed the application of GIS in BIM environments and building information models in the geospatial domain. For example, (Peña-Mora*, et al*, 2010) recognised the need to integrate different IT technologies such as GIS and digital building information, in one reliable platform for emergency response management. Also, (Choi *et al.* , 2008) established a prototype system to share the building information models among indoor GIS applications.

2.10 Case studies in the construction industry

This section describes two case studies in the UK which confirm and explain a successful implementation and integration of technological paradigms such as GIS, CC, MC, and the IoT. The first case study addresses the integration of numerous stakeholders participating the High Speed 2 (HS2) project via the utilisation of Cloud computing and smart devices. The second case study describes the implementation Artificial Intelligence to increase jobsite health and safety.

2.10.1 Case study: HS2 stakeholders' integration in the UK via Cloud computing

High Speed 2 (HS2) is a planned high-speed railway in the United Kingdom linking London, Birmingham, the East Midlands, Leeds, Sheffield and Manchester. It would be the second high-speed rail line in Britain, after High Speed 1 (HS1) which connects

London to the Channel Tunnel. Work on the first phase is scheduled to begin in 2017, reaching Birmingham by 2026, Crewe by 2027, and fully completed by 2033.

Mott MacDonald was appointed to provide civil and structural services for HS2. They were also appointed to two work packages: covering environmental and land referencing services. One of the main challenges for this project during the planning stage was to create a central, trusted source of real-time information which stimulates close collaboration and communication between all stakeholders, wherever in the world they may be. The magnitude of information in this project that needs to be collected, curated and controlled during the planning stage seemed completely unworkable. According to Louise Walker, Mott MacDonald HS2 GIS manager:

> *"Land referencing had not been carried out in the UK on this scale for many years. It is a process whereby the client's team gains a full understanding of the geography, ownership rights, access and a host of other environmental factors, which are vital to progressing to the detail design stage. In this case, the scope involved 3000 land owners and more than 5000 individual land titles, covering 220 km^2"*

To address this challenge, Mott MacDonald had to work with 30 external sub-consultancies, which generated numerous geological, historical, ecological and land ownership data. All this information represented in a range of spatial and non-spatial formats such as 3D models, GIS models, spreadsheets, documents and images. Since the 30 external sub-consultancies were scattered all over the UK and ranged from small businesses to large firms, the challenge was how to enable a team of this size to collaborate on such a large project.

The existing options were not viable. The first one consisted of duplicating and synchronising all data and then upload it at all offices of all partners involved in the project; this would have created massive issues with version control and it would have recurred in high software licensing costs. The second option was for most of the partners share the same physical work space, and although this would have enhanced cross-communication between the project's stakeholders it was not a realistic option. According to Andrew Sheekey, Mott MacDonald GIS manager, the selected approach for information sharing was the following:

"… we built a system that combines GIS, BIM and big data processes to host all the information necessary to support decision making, technical assessment and problem solving."

This new system was divided into two applications that have been successfully deployed on the HS2 project: Gigi and Apollo. Gigi consists of a platform of 2.1TB of data and 400 users from 24 different organisations working on HS2. It provided a visual display of over 1500 datasets from more than 80 suppliers covering 14 environmental topics. The 2.1TB of information uploaded to Gigi were compound by 1600 layers of information. Gigi is also linked to CAD and BIM data models to keep design team information up to date. Apollo facilitated land referencing tasks, such as establishing and recording proof of land ownership, together with facilitating land access and environmental surveys. Both Apollo and Gigi enabled information to be managed, checked and edited at any time by a desktop computer or via tablet or smart phone.

2.10.2 Case study: Reduced jobsite risk with Smartvid.io

Artificial Intelligence is now being applied across industries at many levels of technological sophistication. Some companies are moving beyond the capability of training AI to observe to training AI to predict the future. This case study wanted to understand if this new frontier in AI, predictive analytics could be applied to construction safety risk?

In this case study Smartvid worked with the company Suffolk to reduce risk in their projects by implementing their AI engine, nicknamed “Vinnie” which already analyses photos coming from construction management systems like Autodesk BIM 360, OxBlue site cameras, and Procore.

Smartvid’s AI engine has the following capabilities:

- Set up integrations with apps already in use on your jobsites like Autodesk BIM 360 or Procore
- Pull photos from site cameras like OxBlue software.
- Use the mobile app to take new pictures in the field - and automatically sync to the cloud!
- Instantly find up to 40+ visual objects, including *key indicators of risk*
- Customize a list of words, phrases or acronyms to “listen” for in narrated videos or photos with audio captions
- Run safety reports to see trends, find problem areas and promote a positive safety culture
- Review and share images flagged by our AI with project teams
- Reduce incident rates and improve safety performance

According to Suffolk’s Executive Vice President:

"There is demonstrable opportunity to control hazards and improve safety performance by deploying resources to those sites where elevated risk is predicted."

This case study is only possible thanks to an existing implementation of smart devices to collect images in the jobsite. Smart devices can be useful tools for gathering large datasets in construction projects. This case study concluded that the company's data which is gathered from smart devices is a rich source for making safety observations; Also, there was a high value in the time it took to take advantage of the existing data of the company with an integration of Smartvid's AI engine.

2.11 Summary

This chapter presented a thorough review of the literature on smart devices and the related paradigms and technologies which are: IoT, AI, MC, CC, BIM, AR and GIS. It was found that the paradigm of the smart devices is contain within the paradigm of the IoT which also relates to the other paradigms.

The IoT proposes the interconnection of any object or device into a large network of interconnected devices. It relies on smart devices to create new concepts such as smart homes, smart cities or the Industry 4.0. It was also found that the UK has embedded the IoT into its strategic development plan known as "Digital Built Britain" (HM Government, 2015), showing that the UK acknowledges the importance of maximising efficiency through the integration of IoT into industries such as construction.

The literature showed the building blocks and related technologies to the IoT. As building we can find, sensors, actuators, WSNs and RFIDs. Some technological paradigms which are worth mentioning around IoT are: Ubiquitous computing, pervasive computing, 5G cellular network, IoNT and IoUT.

The intersection between IoT, MC and CC generate interesting areas of research such as MCC, Mobile IoT computing and Cloud IoT computing. Cloud and mobile computing have also shown to be a relevant technology behind smart devices. CC and MC were key to provide ubiquitous data access and mobility to users of the construction sector.

The utilisation of smart devices and the paradigm of the IoT generates a lot of data such as images, videos, text and audio. All this information enables construction companies to implement AI and Big data analytics to enhance the processes of construction companies. A valuable example is shown in section 2.10.2 where a case study of the implementation of AI for evaluating the safety conditions of projects was presented.

The review of the literature revealed the challenges and drivers for implementing technologies such as AR and BIM. It was found that cost, hardware issues and development of applications were the key challenges for implementing AR in construction, whereas the reduction of errors and cost, and pervasiveness were key drivers for implementing AR.

This chapter has shown all the dimensions around smart devices in the context of the Construction industry. An implementation of smart devices has various layers of complexity. A construction company can provide smart devices to their employees, or it can establish a whole infrastructure of CC behind it with a shared data environment and Big Data analytics. The following chapter describes the research methodology implement throughout the whole research process.

Chapter 3: Research Methodology

3.1 Introduction

This chapter reports on the research methodology utilised on this investigation. An overview of the research process, data collection strategies and data analysis techniques are presented and discussed. Overall, chapter also explains and justifies the process performed to ensure the trustworthiness of this study

This chapter is structured in five sections: First, section 3.2 describes an overview of the whole research process. Then, section 3.3 presents the research design for this thesis. The research design explains the research ideology and philosophy behind this investigation. Also, the research design justifies the research approach, methods and techniques chosen for this research. Section 3.4 explains the research undertaken in this investigation in a chronological order. Section 3.5 addresses the challenges and lessons learned through in the investigation. Finally, section 3.6 summarises the whole chapter.

3.2 Overview of the research process

The research process was broken into five key stages. These stages are literature review, pilot data collection, main data collection, data analysis, and compilation of output. Critically reviewing the literature was the initial step to establish an initial background of the existing knowledge around the topic. It also helped established which research questions could be answered through the analysis of literature and which ones still required further research to be answered. A literature review is a systematic A literature review is a systematic and reproducible method for identifying and synthesising the existing body of recorded work generated by researchers or scholars (Fink, 2013).

The second stage consisted on performing a pilot qualitative data collection. A pilot study is a preliminary study of a complete survey or interview. General applications of pilot studies can be summarised in four areas: (1) to find problems and barriers related to participants recruitments, (2) being engaged in research as a qualitative researcher, (3) assessing the acceptability of observation or interview protocol and (4) to determine epistemology and methodology of research (Janghorban, 2014). This stage allowed to refine the interview protocol and research techniques implemented in the main data collection. The pilot study consisted of fifteen semi-structured interviews to professionals of the construction industry in the Dominican Republic. Justification about the sampling technique is provided in this chapter.

The third stage was the main qualitative data collection which consisted of ten semi-structured interviews in the Dominican Republic and fourteen semi-structured interviews in the United Kingdom. This stage counted with the observations taken during the pilot study. The number of interviewees during the main data collection was determined based on the principles for data saturation theory explained by Francis *et al*. (2010), which are further explained in section 3.4.3. Subsequently, the data analysis was performed, relying in thematic analysis as its main tool. As part of the data analysis a strategic framework was developed and validated. Chapters 4 to 9 detail the findings obtained from the qualitative data collection and analysis.

The final stage was the compilation of the research output, which consisted of compiling and proofreading all the findings obtained throughout the research process.

During this stage the findings found from the data analysis were corroborated with the existing body of knowledge through a critical review of the literature.

3.3 Research design

This section describes the distinct elements which compose the design of the research process of this project. Said elements are research philosophy, approach, strategy and methods. Figure 3.1 shows the selected methodologies for each aspect of the research design. The following sections will explain and justify these selections.

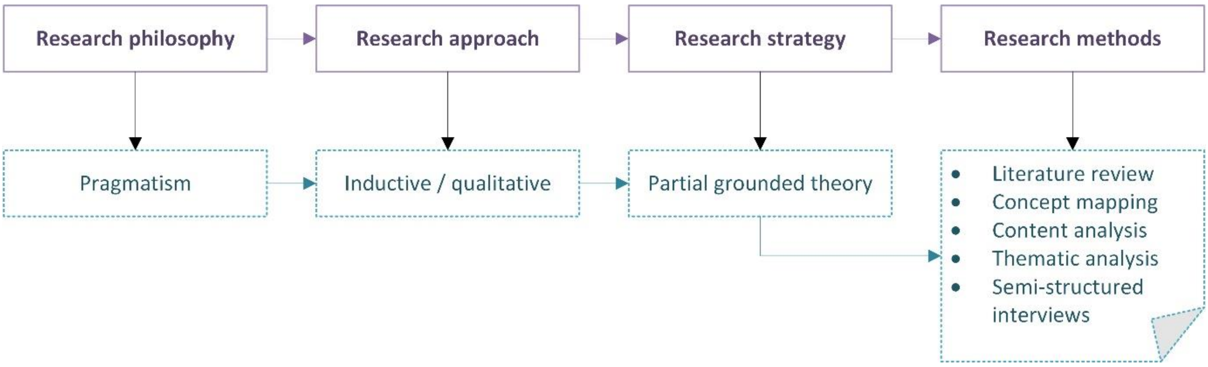

Figure 3.1: Structure of research design

3.3.1 Research Design typology

Among other theories, this investigation follows the research design typology model developed by Strang (2015) grounded in pragmatic theory after conducting multiple interviews and collecting feedback from multiple organisations and academic researchers on their research design needs (see Figure 3.2).

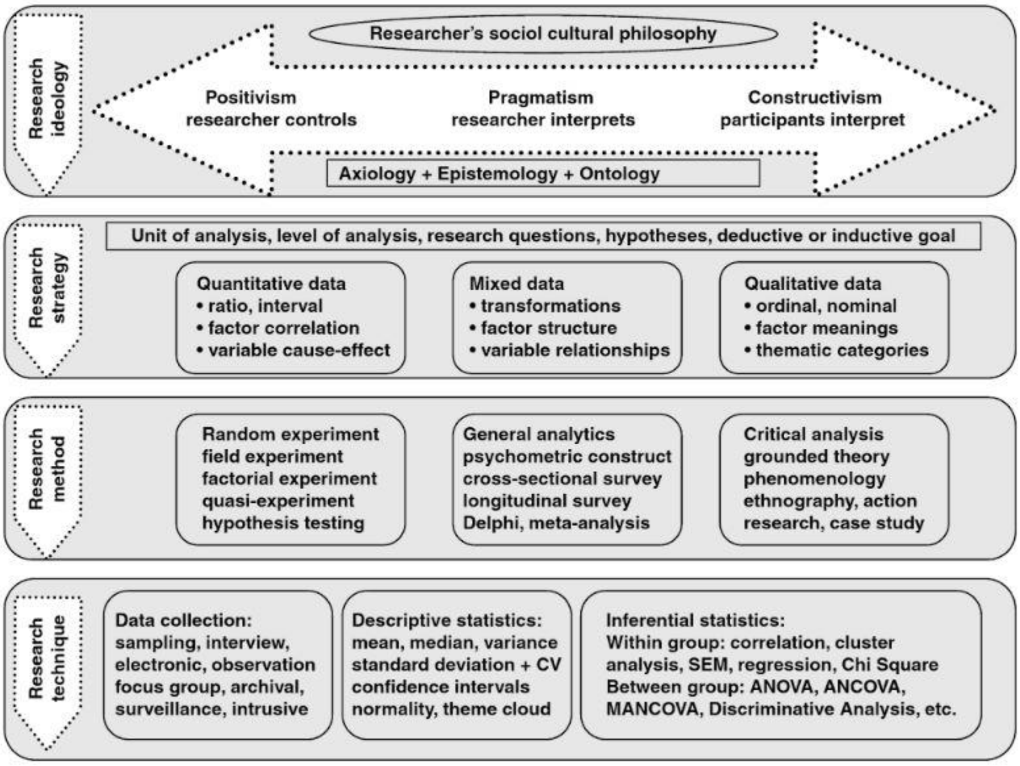

Figure 3.2: Research design typology

See Strang (2015)

The continuum explained in Figure 3.2 has four levels, namely: Research ideology, research strategy, research method and research technique. Each level is independent and is not linked left versus right with any of the other levels. This feature makes this typology unique; other theories attempt to link the researcher's beliefs with the research methods to be implemented. One example is the Information System research paradigms by Khanzanchi and Munkvold (2003) where each research paradigm has an ontological, epistemological and methodological level, each one linked depending on the selected paradigm.

This investigation follows the research typology developed by Strang (2015) as the main guide for the development of the research ideology of this study. The following sections will define the research ideology, strategy, methods and techniques selected for this study.

3.3.2 Research ideology and philosophy

Research ideology refers to how the researcher thinks and appreciates a set of knowledge, weather it is quantitative or qualitative (Strang, 2015). According to Strang (2015) there are two main purposes behind the selection of a research ideology: First, is for researchers to define their philosophical view or research perspective and second, it serves as a baseline for researchers to understand each other's viewpoints and publications. Within the Research ideology layer there are three factors: Axiology, Epistemology and Ontology.

(Petrescu, 2015) defines axiology as "a descriptor of subjective ideological systems of individual values". Axiology can be considered as the collective term of ethics and aesthetics. According to Strang (2015) it refers to the theory of beliefs, including moral beliefs and how these impact ethics. A good example of different axiological foundations between cultures is how some research cultures believe it is incorrect to conduct experiments with specific animals. In simplified terms axiology refers to what the researcher considers as right or wrong (ethics) and good or bad practice (aesthetics).

Epistemology can be simply defined as the study of knowledge (Benzel, 2018). Strang (2015) refers to epistemology as the theory of knowledge, encompassing the disciplinary terminology for communicating knowledge between scholars. The epistemology of a research addresses a specific terminology for the investigation, which may vary depending on the discipline of the research.

The ontology factor addresses the cognitive analysis of the researcher. Ontology refers to the foundational beliefs of a researcher of what is real or not. According to Strang (2015):

"ontology impacts where a researcher looks for data and then what the researcher considers real versus imagined, true versus false."

These factors are a sociocultural and philosophical decomposition of the ideologies of a researcher. Ultimately, a researcher's ideologies can be assembled together and named according to its philosophical knowledge beliefs and values. Consequently, there are three philosophical positions within the research ideology continuum showed in Figure 3.2: Positivism, Pragmatism and Constructivism.

According to Encyclopaedia of Modern Political Thought (2013):

"Positivism is a philosophy that argues that only the scientific method can yield reliable knowledge, and that this method should be applied to social phenomena as well as to the natural world".

It is one of the oldest research philosophies which according to Crotty (1998) refers to being evidence and theory driven. Strang (2015) states that, first, this is an individual posture of each researcher and second, pure positivism is rarely implemented, whereas Post-positivism is more frequently utilised by fact-driven researchers because it represents the thinking after positivism (Creswell, 2014). Positivist collect quantitative or mixed data, being deductive researchers instead of inductive.

Pragmatism is a more flexible approach than positivism. It allows the researcher to collect a first round of quantitative or qualitative data types, then refine the theory and future data collection depending on the previously collected data (Strang, 2015). According to the definition of pragmatism given by Emirbayer and Maynard (2011) the researcher must be flexible with the selected methods and techniques. Instead of applying a single accepted research method, a pragmatic researcher would leave the theory guide the investigation. Pragmatic researcher utilises either quantitative, qualitative or mixed method approach.

Constructivism is considered by some writers as qualitative, mixed or participatory approach. In a constructivist research the participants interpret the data giving sense to the investigation. According to Strang (2015) in a constructivist research the participants and researcher will give sense to the collected data, hence, researchers must record the participant's responses or behaviours. One important difference between a pragmatic and constructivist approach is that in the first the researcher interprets whilst in the latter the participants interpret.

There is very few background researches for this investigation, which requires a flexible approach for collecting data. Due to the nature of this investigation, this thesis follows a pragmatic ideology. A pragmatic research allows the researcher to be flexible about the methods and techniques used for data collection depending on the nature of the research. As mentioned previously a pragmatic approached does not necessarily means that a mixed methodology will be adopted but instead refers to the way the researcher selects the approach for data collection and analysis.

In a pragmatic worldview the researcher focuses on methods, emphasizing the research problem and use all approaches available to understand the problem (Rossman and Wilson, 1985). A pragmatic researcher has a freedom of choice. In this way, researchers are free to choose the methods, techniques, and procedures of research that best meet their requirements (Creswell, 2014).

3.3.3 Research approach

Performing a pragmatic study means the researcher interprets the results. It also means there is flexibility about the selected research approach. The selection of a qualitative approach requires justification and explanation against a quantitative one.

A qualitative approach is suited for an exploratory research; with variables unknown, where the context is relevant and there is few background theories for the study. This approach is by nature inductive, which means that it generates a theory, but may also incur into bias if it is not properly designed. The results are shown as rich narrative which are context dependent and are less generalisable and case-specific.

A quantitative approach is suited for a research in which there is an existing body of literature, known variables and existing theories. The epistemological orientation of this type of research is usually positivism with the believe that there is only one truth or one Universe. This approach is by nature deductive, which means that it pursues to test a theory. A quantitative approach uses numbers as main element of analysis; hence, the results are always shown in terms of statistical analysis, which is context free and separates the researcher from the study. The data analysis intents to establish relationships or correlation.

The selection of a qualitative, quantitative or mixed methodology requires the understanding of the background theory on the field of study and the nature of the study. This study aims to develop a strategic framework for the implementation of smart devices in the construction industry, such framework can be considered as a theory. This investigation surveys the construction industry and attempts to generate a framework based on the perception of professionals in the industry. In the light of these facts this investigation adopts a qualitative research approach based on semi-structured interviews.

3.3.4 Research strategy

As a mean to drawing a better understanding in the selection of the right research approach researchers often utilised Saunder's research onion as a tool for located their research within the right approach (See Figure 3.3). The research 'onion' is used by Saunders *et al.* (2009) for explaining the selection process of a data collection and data analysis technique.

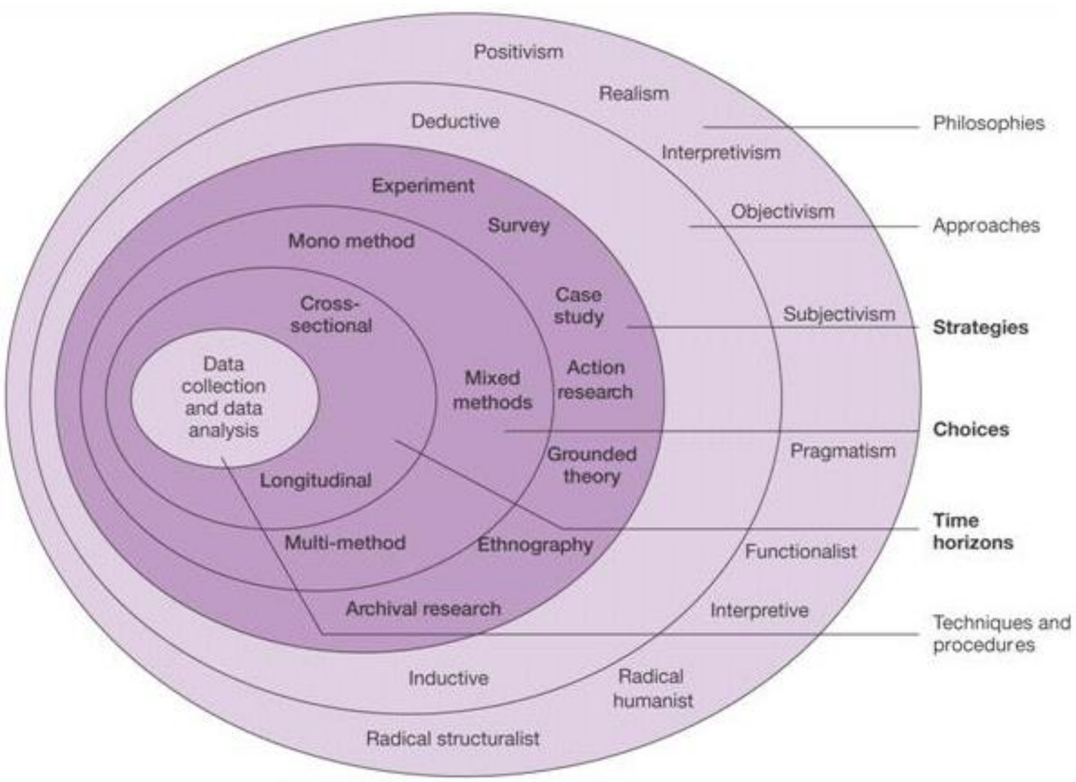

Figure 3.3: The research 'onion'.
See Saunders et al. (2009)

By selecting a pragmatic research ideology with a qualitative approach, the implementation of grounded theory seems appropriate at first glance. Grounded theory emerged in the early 1960's from the research of Sociologists Barney G. Glaser and

Anselm L. Strass. They published their approach in the publication called “The discovery of grounded theory”, in which they proposed that systematic qualitative analysis has its own logic and could generate theory (Charmaz, 2014).

After analysing Glaser (1978); Strauss (1987) and Charmaz (2014), this investiation highlights the defining components of grounded theory as the following:

- Simultaneous involvement in data collection and analysis
- Constructing analytic codes and categories from data, not from preconceived logically deduced hypotheses.
- Using the constant comparative method, which involves making comparisons during each stage of the analysis.
- Advancing theory development during each step of data collection and analysis.
- Memo-writing to elaborate categories, specify their properties, define relationships between categories, and identify gaps.
- Sampling aimed toward theory construction, not for population representativeness.
- Conducting the literature review after developing an independent analysis.

Based on these principles grounded theory is a dynamic methodology which requires constant comparison and revision, and aims at creates and reviews theory, and using such theory for updating the data collection process which is always qualitative.

In the establishment of Grounded theory Glaser (1978) and Strauss (1987) invited their readers to use grounded theory strategies flexibly in their own way. Researchers such as Charmaz (2014) view grounded theory methods as a set of principles and practices which can implemented depending on the investigation. Subsequently, this research will use some of the methods and principles of Grounded theory such as semi-structured interviews and content analysis to collect and analyse the data. Subsequently the collected data will be used for the development and validation of the already mentioned framework.

At this point, it has been clarified that this is a pragmatic research which follows a qualitative inductive approach and uses grounded theory methods for data analysis. The following section explains the selected research methods for this investigation.

3.3.5 Research methods

3.3.5.1 Selection of research methods/techniques

The following research methods were implemented: Literature review, concept mapping, semi-structured interviews, content and thematic analysis. Semi-structured interview was the selected method for data collection, whereas thematic analysis was used for qualitative data analysis. Content analysis was used to assist the quantitative analysis on the literature. This section explains the criteria behind that selection, also justifying these methods as the most appropriate for this investigation.

When selecting an appropriate research method for data analysis grounded theory offer valuable techniques and good practices, but its implementation requires a constant iteration of the data collection tools which in the case of this investigations are semi-structured interviews. Performing semi-structured interviews within the framework of grounded theory requires a constant data analysis during the data collection process, whereas this research focused on collecting the data in an initial pilot study, and subsequently enhance the semi-structure interview techniques.

Creative research based primarily on opinion and interviewee's experiences and speculation, useful in building a theory that can subsequently be tested. Places greater emphasis on the perspective of the researcher. On one side semi-structured interviews promote the creation of new ideas and insights, building theory to be subsequently tested. While on the other hand it is by nature unstructured, subjective nature and with likelihood of biased interpretations.

The use of qualitative descriptive approaches such as thematic analysis is suitable for studies where the researchers wish to employ a relatively low level of interpretation, in contrast to grounded theory or hermeneutic phenomenology, in which a higher level of complexity exist in the interpretation of data (Vaismoradi, 2013).

3.3.5.2 Content and thematic analysis

Both content analysis and thematic analysis share the same aim of examining narrative materials by breaking the text into relatively small units of content and submitting them to descriptive treatment. Content analysis and thematic analysis allow for a qualitative analysis of data. With content analysis, it is possible to analyse data qualitatively and at the same time quantify the data. Content analysis uses a descriptive approach in both coding of the data and its interpretation of quantitative counts of the codes (Vaismoradi, 2013). On the contrary, thematic analysis provides purely qualitative, detailed, and nuanced account of data (Braun and Clarke, 2006).

Table 3.1: Processes of data analysis in thematic analysis and qualitative content analysis
Adapted from Vaismoradi (2013)

Analysis phases and their descriptions	
Thematic analysis (Braun and Clarke, 2006)	Content analysis (Elo and Kyngäs, 2008)
Familiarising with data	*Preparation*

Transcribing data, reading and rereading the data, noting down initial ideas.	Being immersed in the data and obtaining the sense of whole, selecting the unit of analysis, deciding on the analysis of manifest content or latent content.
Generating initial codes Coding interesting features of the data systematically across the entire data set, collating data relevant to each code.	*Organising* Open coding and creating categories, grouping codes under higher order headings, formulating a general description of the research topic through generating categories and subcategories as abstracting.
Searching for themes Collating codes into potential themes, gathering all data relevant to each potential theme.	
Reviewing themes Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic map.	
Defining and naming themes Ongoing analysis for refining the specifics of each theme and the overall story that the analysis tells, generating clear definitions and names for each theme.	
Producing the report The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a report of the analysis.	*Reporting* Reporting the analysing process and the results through models, conceptual systems, conceptual map or categories, and a story line.

Thematic analysis is a method for identifying, analysing and reporting themes (patterns) within qualitative data by organising and describing the dataset in detail (Braun and Clarke, 2006). It is widely used in the research community, and although in the recent past there was no agreement about its definition and methodology of implementation (Braun and Clarke, 2006), more recent investigations have shared some valuable insight into the methodological aspects of thematic analysis. One example is Vaismoradi (2013), who described and discussed the boundaries between content analysis and thematic analysis, as well as a classification of thematic analysis as a descriptive qualitative approach to data analysis.

As for the steps to follow in thematic analysis they are detailed in Table 3.1. The first step is familiarising with the data. Subsequently, the researcher needs to generate codes and search for themes or patterns, after a thorough review of themes and naming conventions, an academy report is drafted.

3.3.5.3 Literature review

A literature review is fundamental to all research methods. It is a systematic and explicit method for evaluating the existing body of completed and recorded work produced by researchers, scholars and practitioners (Fink, 2013).

The review of literature provides and demonstrates appreciation and an understanding of the state of knowledge of the topic and its context. It should provide the summary of the 'state of the art' for the extent of knowledge and issues regarding the topic. A literature review can be considered as a critical survey of the already available published work on researched topic.

Following Fink's guide for performing a literature review (Fink, 2013) the following seven steps approach lead the process of reviewing and synthetizing the literature:

1. Selecting a research question
2. Selecting bibliographic or article databases
3. Choosing search terms
4. Applying practical screening criteria.
5. Applying methodological screening criteria
6. Doing the review
7. Synthesizing the results

3.3.5.4 Semi-structured interviews

A semi-structured interview is designed to ascertain subjective responses from persons regarding a particular situation they have experienced (McIntosh and Morse, 2015).

The type of data derived from semi-structured interviews cannot be obtained from structured questionnaires, participant observation or analysis of the literature (McIntosh and Morse, 2015). It is an in-depth data about a phenomenon which can be answer from the participants’ experience.

The sampling technique used for gathering the interview respondent was Snowball sampling. A sampling procedure may be defined as snowball sampling when the researcher accesses new respondents through contact information that is provided by other respondents (Noy, 2008). In the scope of the research a “respondent” is a professional in the field of Construction who participates in the semi-structured interview. Snowball sampling is one of the most employed method of sampling in qualitative research in various disciplines across the social sciences (Noy, 2008). This investigation relies on its effectiveness and resourcefulness to gather experienced respondents. The process of snowball sampling occurs in the following way: (1) After performing a semi-structured interview the researcher inquiry for experienced professionals in the Architecture, Engineering and Construction (AEC) sector who might contribute to the study; (2) Respondents refer the researcher to other prospective respondents, who are contacted by the researcher and then refer her or him to yet other prospective respondents. Hence the evolving ‘snowball’ effect.

3.3.6 Unit of Analysis

The unit of analysis is the element on which data is analysed and for which findings are reported. It is the representation of the entity under study and to which the results will be applied. The unit of analysis adopted for this study is the 'construction sector' and the sub-unit is 'individual employee' who is involved in the implementation of smart devices in construction projects.

3.3.7 Justification of comparative research

Comparative research is the art of comparing two or more things with a view to discovering something about one or all of the things being compared (Heidenheimer *et al.*, 1990). The aim of comparative research is to make comparisons across different countries or cultures. The major problem being that the data sets in different countries may not use the same categories or define categories differently, meaning that sometimes within-country differences are obscured, since in some national units, internal diversity may be greater than the diversity observed when comparing countries with one another (Lor, 2010).

Comparative research can take many forms. Two key factors are space and time. Comparisons within countries, contrasting different sectors, cultures or industries can be very constructive. On the other hand, historical comparative research can compare different time-frames.

This investigation attempts to perform a spatial cross-national comparison between a developed country and a developing country. The results will provide a wider insight into the strategic points for a successful implementation of smart devices in different socio-economic environments. To ensure that each country is evaluated properly, data saturation will be achieved in the data collection process of both countries. In studies that use semi-structured interviews, sample size is justified on the basis of interviewing respondents until data saturation is obtained (Francis *et al.*, 2010).

3.4 Research undertaken

This section describes all the stages of the research undertaken. Figure 3.4 shows a diagram with all the research undertaken chronologically. Stage 1 consisted of a critical review of literature; Stage 2 was a pilot data collection based on semi-structured interviews in the Dominican Republic; Then, the main data collection was performed on stage 3; Afterwards, stage 4 was the analysis of the data collected in the previous stages; Finally, on stage 5, a strategic framework for the implementation of smart devices was developed and validated.

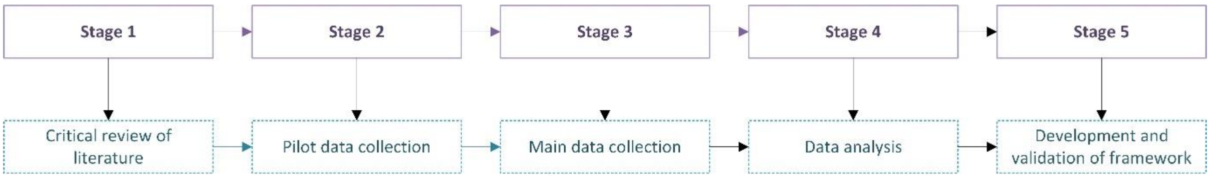

Figure 3.4: Diagram of research process

3.4.1 Critical review of literature

Following the recommendations of Fink (2013) the research team made sure to perform a literature review in a systematic and reproducible which synthesises the existing body of recorded work generated by scholars around the world. The literature was searched using the online services Google Scholar and Science Direct. The main advantages of these services are ease of use and broader universe of cited and citing items (Franceschet, 2010).

The selection of peer-reviewed journal articles, conference papers, books and other academic publications was based on a selection criterion which included the main keywords around the topic of smart devices. An exploratory research was performed using the keywords “smart device”, “mobile device”, “Internet of Things”, “construction industry” and “Construction industry”.

Google trend was used to refine the search criteria of academic publications. The Google trend data presented in Figure 3.5 and Figure 3.6 is adjusted and proportionate to the time and location of the query. Each data point is divided by the total searches of the geography and time range it represents, to compare relative popularity. Otherwise places with the most search volume always be ranked highest. The resulting numbers are then scaled on the Y-axis from 0 to 100 based on a topic’s proportion to all searches on all topics.

The keywords for beginning the literature review were “smart device”, “mobile device” and “Internet of things”. As can be seen in Figure 3.5 from the year 2013 there was a relevant growth in the trends o few search popularities for the term “Internet of Things”. Consequently, this study adjusted the selection criteria for the initial literature review to publications from the year 2012.

The selection of the terms “smart device” and “mobile device” required the following reflexion: Stojkoska and Trivodaliev (2017) highlights Smart devices as the core devices present in the IoT. On the other hand, Lanotte and Merro (2018) mention both smart devices and mobile devices. Bisio et al. (2018) mentions only mobile devices as the devices present in the IoT. Although there is a lack of consensus between which term is the right one to be used when referring to the IoT, the etymologic meaning of these term associates the term “mobile devices” to devices with a high degree of mobility, whereas the term “smart device” implies certain level of embedded cleverness in the device. Based on the inherent characteristics of these terms this investigation chooses the term Smart device as the name for the objects present in the IoT, thus agreeing with Stojkoska and Trivodaliev (2017). Nevertheless, according to the Google’s web search trends presented in Figure 3.6, the term “mobile device” shows a higher popularity for when compared with the term “smart device”, this encourages the utilisation of this keyword in the filters of the inclusion criteria implemented in this research. Ultimately this is how both keywords “smart device” and “mobile device” were selected and independent searches for peer-reviewed journal articles has been done via databases.

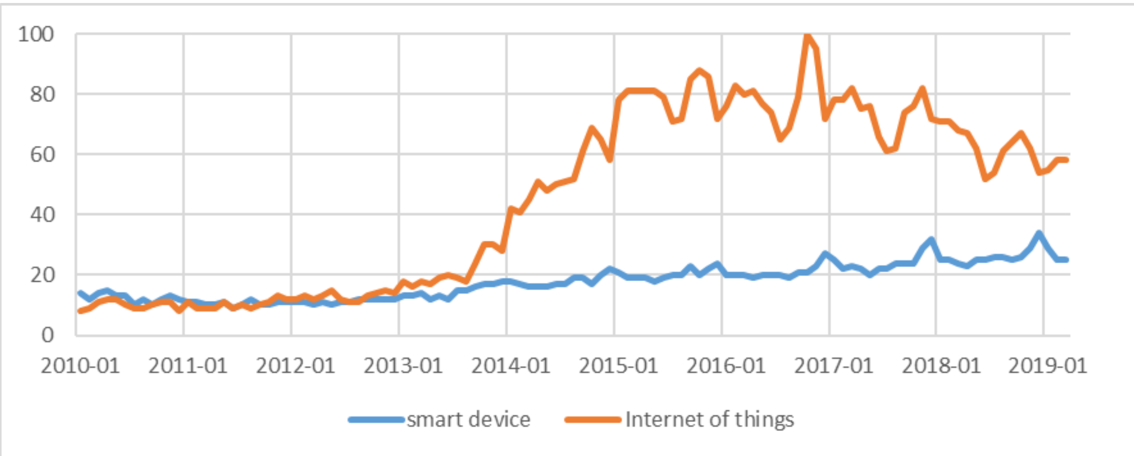

Figure 3.5: Interest over time according to Google trends since 2012 for terms Smart device and Internet of Things

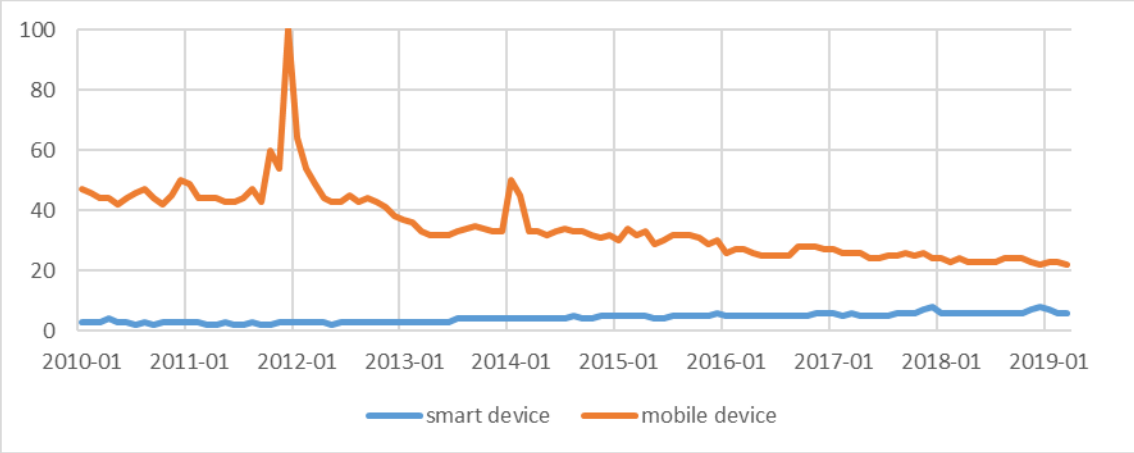

Figure 3.6: Interest over time according to Google trends since 2010 for terms Smart device and Mobile device

The process of selecting the relevant literature kept going until the end of this study. In addition, we followed the guidelines of White and Marsh (2006) for performing a systematic content analysis to create themes for regarding the main paradigms and technologies around the topic of smart devices. Concept mapping technique was used to graphically conceptualise the knowledge gathered from the literature. The software Microsoft VISIO was used to create diagrams with the purpose of drawing a better understanding of the knowledge gathered from the literature.

This study found the following themes as relevant and necessary to be mentioned in the literature: Internet of Things (IoT), Big Data, Artificial Intelligence (AI), Augmented Reality (AR), Building Information Modelling (BIM), Geographical Information System (GIS), Cloud computing (CC), Mobile Computing (MC). The relationship between these terms and smart devices is discussed in chapter 2. Furthermore, chapter 2 also discusses several relationships between these paradigms, like for example the relationship between AI and Big data, or between, CC, IoT and MC.

The literature review and content analysis also allowed this investigation to build Chapter 4, which presents a conceptualisation of the term smart device within the paradigm of the IoT.

3.4.2 Pilot data collection in Dominican Republic

After completion of the initial review of the literature, it was found that our research question still needed to be answered. The purpose of this study was (1) to gather information about the utilisation of smart devices in the construction industry of the Dominican Republic, drivers, challenges and critical success factors for the implementation of smart devices. (2) To refine the data collection techniques used in this investigation.

The study consisted of semi-structured interviews to professionals on the Construction industry. Fifteen professionals from ten different companies were interviewed. The data collection required the interviewer to travel to the Dominican Republic for 3 weeks. The initial sampling technique was critical case sampling; this is a type of purposive sampling technique that is particularly useful in exploratory research which allows establishing valid generalisations (Palinkas *et al.*, 2015). Snowball sampling was subsequently used to access new respondents through contact information that was provided by other respondents. Snowball sampling is one of the most employed method of sampling in qualitative research in various disciplines across the social sciences (Noy, 2008).

The selection of the sample size considered different the experience of previous investigations. Mason (2010) analyses qualitative studies from PhD thesis and explains that such studies may have between four and eighty-seven interviews, with a mean value of twenty five. Creswell and Poth (2017) recommend twenty to Sixty interviews for a study of this kind. The literature provides an idea of a common number of interviews for qualitative research based on semi-structured interviews, nevertheless, the methodological process for determine if the sample size is adequate is based on data saturation as explained by (Mason, 2010) and (Creswell and Poth, 2017). Therefore, sample size is justified on the basis of interviewing respondents until data saturation is obtained (Francis, 2010).

Any research that involves human participation requires ethical approval from the researcher's institution. An ethical approval from was filled by the lead researcher and then through the research supervisor it was submitted for approval to the ethics committee of the School of Architecture and Built Environment, Faculty of Science and Engineering at the University of Wolverhampton.

The interview questions were designed to probe the critical factors for a successful implementation of smart devices in the industry. Initially, the interviewees were asked: What are the main utilisations given to smart devices? This is an introductory question aimed at drawing understanding on the scope of the concept of smart devices in the local sector. Subsequently, the organisations were asked: What are the critical success factors for a successful implementation of smart devices in the construction industry? This question attempted to understand the critical points for successfully implementing smart devices.

The interviews were performed from December 2016 to January 2017; the duration was fifteen to thirty minutes. The interviews were held in the city of Santo Domingo in the Dominican Republic.

The original idea of the study was to do the interviews and then use them to refine a survey questionnaire which would be part of the study. After performing the interviews, the data found made the survey unnecessary since the interview provided a deeper and more relevant picture of the Dominican construction industry.

The interviews were recorded and subsequently transcribed, producing a full verbatim transcript. The transcription process did not consider factors such as voice inflection, laughter, joviality, or any other nuanced behaviour.

The implementation of a pilot study led to improvements in the data collection process. The following modifications were made to the subsequent main data collection:

- The format and order of the interview questions was changed. The questions were properly sectioned and numbered.
- The order of the questions was updated based on pattern in which certain questions commonly lead to other questions. For example: It was found that a question about the utilisation of smart devices usually leaded to a question about the organisation’s competitiveness.
- The term “smart technologies” for updated for the term “technologies related to smart devices”
- The coding used for data analysis during the pilot study updated. The new coding is explained below.

During the pilot study, the following code was used:

DATA COLLECTION NUMBER – INTERVIEW – NUMBER – PROFESSION

1. Data collection number: 1DC, 2DC
2. Interview: INV
3. Number: 001 – 015
4. Profession: ENG, ARQ

This code had four terms. Since all the files are interviews, then the second term will always be interview, hence there will not be any distinction between the "INV" term in 1DC-**INV**-001-ENG and 1DC-**INV**-002-ENG.

The new code is the following:

DATA COLLECTION NUMBER – COUNTRY – NUMBER – PROFESSION

1. Data collection number: 1DC, 2DC
2. Country: DR, UK
3. Number: 001 – 025
4. Profession: ENG, ARQ

This new coding system will allow the files to be sorted in a more meaningful way for the project.

To summarised, the pilot study showed an initial insight into the Dominican Republic construction industry. It was an exploration which relied on semi-structured interviews as its main tool to gather the opinion of professional in the Dominican Republic AEC industry. This study also contributed with enhancements in the protocol for the semi-structured interviews.

3.4.3 Main data collection in the United Kingdom and the Dominican Republic

The purpose of this study was to gather information regarding the research questions established in this study. This stage of the project surveyed the Dominican Republic and United Kingdom construction industries, regarding the utilisation, drivers, barriers and critical success factors for the implementation of smart devices.

This study was the second phase of the data collection which consisted of semi-structured interviews to professionals on the field of Construction in the Dominican Republic and the United Kingdom. ten professionals from ten different companies were interviewed in Dominican Republic. Whereas fourteen professionals from eleven different companies were interviewed in the United Kingdom. The interviewed were made through face-to-face meetings, skype video calls and phone calls. The interviews gathered in the Dominican Republic will be analysed together with the data collected in during the Pilot study.

The initial sampling technique was critical case sampling; this is a type of purposive sampling technique that is particularly useful in exploratory research which allows establishing valid generalisations (Palinkas *et al*., 2015). Particularly with the Dominican Republic, snowball sampling was used to access new respondents through contact information that was provided by other respondents.

The sample size was based on the principles for data saturation theory explained by Francis *et al*. (2010). First, an initial sample size was determined, and, second, the researcher specified a stopping criterion, which consists of how many more interviews will be conducted, without new shared themes or ideas emerging. For the main data collection, the initial sample size was 10 and the stopping criterion was 3 (same as Francis et al., 2010), which means that in the last three interviews, no new theme should arise.

In addition, Mason (2010) and Creswell and Poth (2017) suggest various sample sizes for qualitative research. Mason (2010) analyses qualitative studies from PhD thesis and explains that such studies may have between four and eighty-seven interviews, with a mean value of twenty five. Creswell and Poth (2017) recommend twenty to Sixty interviews for a study of this kind.

The interview questions were designed to obtain the following elements: Utilisation of smart devices in construction project; key drivers and barriers for implementing smart devices in the construction industry; critical factors for a successful implementation of smart devices in the construction industry. The interviews were performed from November 2017 to March 2018; the duration was fifteen to thirty minutes. There were no ethical issues related to the interviews.

The interviews were recorded and subsequently transcribed, producing a full verbatim transcript. The transcription process did not consider factors such as voice inflection, laughter, joviality, or any other nuanced behaviour.

3.4.4 Data analysis

To assist with the data analysis, a 5-step process based on Creswell's (Creswell , 2013) guide for qualitative data analysis was utilised. These steps are transcription of audio interviews; preparation of transcripts; iterative review of transcripts; coding of transcripts; generations of themes. White and March's approach (White and Marsh, 2006) was also a useful source of guidelines for performing qualitative content analysis and developing an inductive coding scheme. The iterative review and coding of the transcripts yielded a deep understanding of the points made by the interviewees and resulted in the extracting of issues and generation of themes relating to the drivers, challenges and critical factors for a successful implementation of smart devices in the same sector.

The interviewees were Civil engineers and architects with positions that range from resident engineers to Director of the company. The years of experience of the interviewees range from more than 2 to more than 30. Table 3.2 and Table 3.3 show the interviewees' professions, position, company size and years of experience for the construction industries of the Dominican Republic and United Kingdom respectively. Table 3.2 and Table 3.3 show the reference code assigned to each interviewee. This code is used in the chapters 5 to 9 to quote the interviewees. Interviewees from the DR range from DR-01 to DR-25, whereas interviewees from the UK range from UK-01 to UK-14.

Table 3.2: Demographic information for interviewees of the Dominican Republic

Code	Profession	Position	Company size	Sector	Experience in construction (years)
DR-01	Civil engineer	Resident engineer	Small	Private	> 3
DR-02	Civil engineer	Resident engineer	Large	Public	> 30
DR-03	Civil engineer	Director	Micro	Private	> 2
DR-04	Civil engineer	Director	Micro	Private	> 12
DR-05	Architect	BIM manager	Small	Private	> 4
DR-06	Civil engineer	Project manager	Medium	Private	> 5
DR-07	Civil engineer	Project manager	Large	Public	> 6
DR-08	Civil engineer	Project manager	Micro	Private	> 4
DR-09	Civil engineer	Resident engineer	Small	Private	> 9
DR-10	Civil engineer	Resident engineer	Small	Private	> 6
DR-11	Architect	Drawings coordinator	Large	Public	> 4
DR-12	Architect	Project designer	Medium	Private	> 4
DR-13	Civil engineer	Project manager	Medium	Private	> 5
DR-14	Architect	Project manager	Medium	Private	> 5
DR-15	Architect	Project manager	Medium	Private	> 10
DR-16	Civil engineer	BIM manager	Medium	Private	> 4
DR-17	Civil engineer	Project manager	Large	Private	> 6
DR-18	Architect	Project supervisor	Micro	Private	> 3
DR-19	Industrial engineer	Logistics Coordinator	Large	Private	> 2
DR-20	Civil engineer	Drilling and blasting engineer	Large	Private	> 1
DR-21	Civil engineer	Contract manager	Large	Private	> 2
DR-22	Civil engineer	Resident engineer	Micro	Private	> 2
DR-23	Civil engineer	Technician	Medium	Public	> 1
DR-24	Civil engineer	Cost analyst	Small	Private	> 1
DR-25	Civil engineer	Drawing reviewer	Large	Public	> 3

Table 3.3: Demographics information for interviewees of the United Kingdom

Code	Profession	Position	Company size	Sector	Experience in construction (years)
UK-01	Computer Scientist	Technical director	Micro	Private	> 6
UK-02	Researcher / Civil engineer	Knowledge Management Specialist	Large	Private	> 2
UK-03	Mechanical engineer	Project manager	Large	Private	> 8
UK-04	Electrical engineer	Signalling design engineer	Large	Private	> 7
UK-05	Technical Architect	BIM MEP technician	Medium	Private	> 2
UK-06	Building Engineer	Structural façade engineer	Medium	Private	> 1
UK-07	Architect	Architectural assistant	Micro	Private	> 10
UK-08	Civil engineer	Graduate Civil engineer	Large	Private	> 1
UK-09	Architect	Part 1 - Architectural assistant	Medium	Private	> 10
UK-10	Architect	Part 1 - Architectural assistant	Medium	Private	> 4
UK-11	Architect	Part 1 - Architectural assistant	Micro	Private	> 1
UK-12	Civil engineer	Principal bridge designer	Large	Private	> 11
UK-13	Civil engineer	Civil engineer	Large	Public	> 2
UK-14	Architect	Part 2 - Architect	Micro	Private	> 3

The DR organisations were classified following the official company classification established in the Dominican Republic by the law 488-08 (*Law No. 488-08*, 2008) from the same country, which divides companies into micro, small, medium and large depending on their number of employees and revenue, this classification is explained in Table 3.4. A total of ten organisations participated in the interviews;

Table 3.4: Classification of companies in the Dominican Republic based on number of employees, capital and revenue

Company type	Company size (No. of employees)	Active capital (In DOP – RD$)	Annual revenue (In DOP – RD$)
Micro	1 – 15	< 3,000,000.00	<6,000,000.00
Small	16 – 60	3,000,000.01 – 12,000,000.00	6,000,000.01 – 40,000,000.00
Medium	61 - 200	12,000,000.01 – 40,000,000.00	40,000,000.01 – 150,000,000.00
Large	>200	> 40,000,000.00	> 150,000,000.00

The UK organisations were classified following the official company classification established in the UK (Wards and Rhodes, 2014), which divides companies into micro, small, medium and large depending on their number of employees. In the UK Micro companies have between 0 and 9 employees; Small companies should have between 10 and 49 employees; Medium companies should have between 50 and 249 employees; Large companies should have 250 employees or more.

3.4.5 Development and validation of strategic framework

A conceptual framework is a network of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena (Jabareen, 2009). A strategic framework can be viewed as an action map. It is a conceptual framework which describes a roadmap towards a specified objective. A very good example is the action plan for the City of Barcelona Spain. Which is compiled into a strategic framework which contains the vision and goals of the city as well as the actions to achieves such goals (Barcelona City Council, 2016).

The empirical findings from the previous stages of the research study and aspects from critical review of literature were taken into consideration in the development of the framework.

The developed framework was validated with five professionals of the construction industry with more than 10 years of working experience.

3.5 Challenges and lessons learned

This section addresses the methodological challenges that arisen throughout the research process. There are different factors that threaten the validity of an investigation, in the case of a qualitative investigation, Malterud (2001) mentions three recurrent challenges when performing qualitative studies, namely, reflexivity; transferability; and interpretation and analysis.

Reflexivity refers to the attitude of attending systematically to the context of knowledge construction, from a researcher's perspective, at each step of the research process. In this research the researcher had to keep a constant reflective attitude for creating conclusions from the findings and literature. The conclusions and recommendations of this research were built throughout the whole research project, rather than at the end of it.

Transferability refers to the possible generalisations of the study. The research team has noticed that expanding the scope of this research to two countries (United Kingdom and the Dominican Republic) provided more reliability in the transferability of the results. The results cannot be directly transferable to every country. But obtaining similar findings on very different countries indicated a good level of agreement in the construction industry regardless of the location. Also, a valuable insight into the importance of culture in construction organisation was found and discussed in Chapter 9.

The interpretation and analysis of the collected data presented a challenge for this investigation. A typical issue in qualitative studies is the misinterpretation of the data due to the researcher's background or philosophy. The guidelines of Creswell (2014) and Malterud (2001) were useful to establish a clear research strategy.

3.6 Summary

This chapter provided a detailed explanation of the research methodology and procedures utilised in the gathering and analysis of the required data to answer the research questions stated by this investigation. Various research methods were used, such as: Critical review of literature, semi-structured interviews, thematic and content analysis. Behind these methods there was a pragmatic research philosophy which allowed the researcher to be flexible about the methods and techniques used for data collection depending on the nature of this research.

The definition of smart device created through an analysis of the literature and the data collected from semi-structured interviews gathered the empirical evidence which explained the drivers, challenges and critical success factors for the implementation of smart devices in the construction industry. This information was used to build and validate a strategic framework for the implementation of Smart devices in the construction industry.

The following chapter commences the discussion of the research findings by discussing the definition of smart device. Chapter 4 to 9 present the findings of this investigation.

Chapter 4: Conceptualisation of the term smart device

4.1 Introduction

This chapter presents a conceptualisation of the term “smart device” created through a review of literature. A clear definition of the concept of Smart device is offered in this chapter. This conceptualisation is done within the paradigm of the Internet of Things (IoT). This chapter presents the terminology found in the literature for addressing smart devices. Also, the key features found in smart devices are presented and discussed.

This chapter is structured as follows: Section 4.2 explains the terminology used in the literature to address what this investigation calls smart device. Section 4.3 presents the key features associated to smart devices. Section 4.4 introduces the concept of smart device and discusses the findings shown in this chapter and their relevance for this study. Finally, section 4.5 shows a summary of this chapter.

4.2 Terminology used in the literature

The literature review showed an inconsistent terminology; many authors used the term “mobile device” for addressing smartphones, tablets and wearables. Other authors use the term “smart device” to referring to the same devices.

Harwood *et al.* (2014) discuss the effect of “smart-devices” on mental health; on the other hand, Koo, Chung and Nam (2015) assess the determinants of perceived usefulness of “smart green IT devices” in reducing electricity consumption. Reading these publications reveal that the authors are referring to similar devices, however, distinct terms are used. The names authors assign to a smart device vary throughout the literature. Various terms we can find are: “smart mobile device” (Ilhan, Yildiz and Kayrak, 2016); “smart metering devices” (Schleich, Faure, Klobasa, 2017); “mobile network devices” (Khan and Khan, 2017); or “mobile handheld device” (Mathew, 2016). Table 4.1 shows the terms used in the literature for smart devices based on the keyword used for searching the databases.

Table 4.1: Term used for referring to smart devices in the literature

From keyword “Smart device”	From keyword “Mobile device”
Smart green IT device	Mobile communication device
Smart metering device	Mobile computing device
Mobile smart device	Hand-held device
Smart mobile device	Mobile hand-held device
Smart objects	Mobile Internet device
Smart sensor-equipped device	Mobile IT device
Smart terminal device	Mobile media device
Smart wearable device	Mobile network device
Tablet smart device	Mobile smart device

4.3 Key features of smart devices

A systematic content analysis revealed distinct themes which describe the key capabilities of the devices addressed by the reviewed papers. The key features that authors in the literature allocate to such devices were grouped in the following terms: Autonomy, connectivity, context-awareness, User-interaction and mobility. The mobility feature comes from the search performed with the keyword “mobile device”, authors particularly assume there is mobility or portability when using the term mobile devices, which is not always the case for smart device. Table 4.2 and Table 4.3 show the selected peer-reviewed journal articles selected in the review and their mention of each of the key features exposed by the content analysis.

Table 4.2: Allocation of peer-reviewed publications into themes from content analysis for keyword "Smart device".

No.	Reference	Year of publication	Connectivity	User-interaction	Autonomy	Context-awareness
1	Medeiros, Holguín, Shin, & Park, 2010	2010			•	
2	Meyer, Yeh, & Tsai, 2012	2012		•		
3	Gans, Alberini, & Longo, 2013	2013			•	
4	Godwin et al., 2013	2013		•		•
5	Zhang et al., 2013	2013	•		•	•
6	Harwood, Dooley, Scott, & Joiner, 2014	2014	•	•		
7	Husnjak, Perakovic, & Jovovic, 2014	2014		•		•
8	Lo, Yu, & Tseng, 2014	2014			•	
9	Chena &Chena, 2015	2015	•	•		
10	Khan, Shrestha, Wahid, & Babyn, 2015	2015	•		•	
11	Koo, Chung, & Nam, 2015	2015				•
12	Azad et al., 2016	2016	•			
13	İlhan, Yıldız, & Kayrak, 2016	2016	•		•	•
14	Muhammad & Devi, 2016	2016	•	•		
15	Najjar & Amer	2016	•		•	
16	Vorderer, Krömer, & Schneider, 2016	2016	•	•		
17	Cheng & Mitomo, 2017	2017	•	•		
18	Li, Chen, & Lu, 2017	2017				
19	Sánchez-Arias, González García, & Pelayo G-Bustelo, 2017	2017	•	•		
20	Schleich, Faure, & Klobasa, 2017	2017			•	
		Total	11	9	8	5

Table 4.3: Allocation of peer-reviewed publications into themes from content analysis for keyword "Mobile device".

No.	Reference	Connectivity	User-interaction	Autonomy	Context-awareness	Mobility
1	Mao, Xiao, Shi, & Lu, 2012	•	•			
2	Ehmen et al., 2012			•		
3	Furthmuller and Waldhorst, 2012	•	•		•	
4	Son, Park, Kim, & Chou, 2012	•	•			•
5	Almuairfi, Veeraraghavan, & Chilamkurti, 2013	•				
6	Zhong, 2013	•	•			
7	Kobus, Rietveld, & Van Ommeren, 2013		•			
8	Melo, Bessa, Debattista, & Chalmers, 2014		•			
9	Richart & Bryant, 2014		•			
10	Wu, 2014	•	•			
11	Suarez et al., 2015		•			
12	Kang et al., 2015	•				

13	Sung, Chang, & Yang, 2015	•	•	•	•	•
14	Sattineni & Schmidt, 2015	•	•			•
15	Markelj & Bernik, 2015	•				
16	Dahri, Gong, & Loewen, 2016	•	•			
17	Mathew et al., 2016		•			
18	Moreira, Ferreira, Santos, & Durao, 2016	•	•			•
19	Vazquez-Fernandez & Gonzalez-Jimenez, 2016	•		•		
20	Mascetti et al., 2016		•		•	
21	Tawalbeh & Eardley, 2016	•				
22	Roberto, Lima, & Teichrieb, 2016	•	•	•	•	
23	Rodríguez, Riaza, & Gomez, 2017		•			
24	Lau et al., 2017	•	•			
25	Khan and Khan, 2017	•			•	
26	Suki and Suki, 2017	•	•			
27	Forehand, Miller, & Carter, 2017	•				•
28	Maryn, Ysenbaert, Zarowski, & Vanspauwen, 2017				•	
29	Xie, Szeto, & Dai, 2017	•	•			
30	Stojanovic et al., 2017		•	•	•	•
	Total	20	21	5	7	6

4.3.1 Autonomy

Within the paradigm of the IoT autonomy is achieved with the implementation of self-managing systems which can perform management and maintenance of their resources intrinsically and internally (Ashraf and Habaebi, 2015). Two fundamental approaches are established in the development of IoT devices, namely, service orientation and agent paradigm. Agent-based computing has enabled autonomy and near-human features among smart devices (e.g.: reasoning and sensing) (Hernández and Reiff-Marganiec, 2015). Agent-based computing is centred around the concept of and agent, which refers to an autonomous, social, reactive entity situated in some environment (Savaglio *et al.,* 2017). The Agent-based paradigm allows modelling multiagent systems, where the agents are networked software entities that can autonomously perform specific tasks on behalf of a user by properly interacting with other agents and with their environment (Fortino *et al.,* 2017).

Ashraf and Habaebi (2015) explains an approach to autonomy in a IoT network where autonomous devices are those enabled to plan, analyse, monitor and execute. These four features follow the autonomic framework developed by Kephart and Chess (2003).

The main idea behind autonomy consists of devices performing tasks autonomously without the direct command of the user. From the analysis obtained from the keyword “Smart device” several references to smart devices were denoting autonomous performance of tasks. For example, Zhang, et al. (2013) explored the factors that play important roles in multitasking scenarios, this requires from smart phones to have certain processing capacity and to perform tasks on the background. In addition, Gans, Alberini and Longo (2013) and Schleich, Faure and Klobasa (2017) intended to use smart devices as “smart” meters or advanced meters to measure information through sensors and send it through a network autonomously. The term Smart device is also used by Najjar and Bani Amer (2016) for a control system utilised in engine cars this if founded on the idea of autonomous performance of tasks.

From the analysis obtained from the keyword “Mobile device” various publications refer to mobile devices as tools that can process information autonomously. Vazquez-Fernandez and Gonzalez-Jimenez (2016) discussed autonomous biometric data processing within mobile devices for face recognition systems. Also, Sung, Chang and Yang (2015) mentions the utilisation of mobile devices for asynchronous tasks.

4.3.2 Connectivity

The concept of connectivity in smart devices refers to establishing a connection to a network of any size; Sometimes the main purpose might be gaining internet access, other times it might be sharing information with other devices on the network.

Nowadays, consumers have access to a vast array of networks; Each network provide an interconnected mesh of devices (Verhoef *et al.*, 2017). It is due to the connectivity provided by smart devices that users have access to transactions in the network (e.g.: social information sharing and video calls).

To draw a better understanding about the inherent variable of connectivity in smart devices, we need to visualise the architecture of the IoT. Wu *et al.,* (2010) presented a well-known 3-layer architecture for Internet and Telecommunications network consisting of perception layer, network layer and application layer (See Figure 4.1). According to Wu *et al.,* (2010) the perception layer is the contact layer with the environment in charge of gathering information; the network layer is the backbone of the IoT which transmit and process data; finally, the application layer is a connects directly with the industry and returns valuable information. Furthermore, Wu *et al.,* (2010) proposed a more specific 5-layer architecture for the IoT, as it is different from the Internet and Telecommunications network. As can be seen in Figure 4.2, both, perception and network layer are still the same. Nevertheless, a processing and a business layer were included to the proposed architecture.

In the IoT architecture proposed by Wu *et al.,* (2010), the network layer remains the backbone of the IoT. It is composed by elements such as Internet network, network management centre, intelligent processing centre, etc. It describes the inherent need for smart devices to have connectivity in order to be part of the IoT.

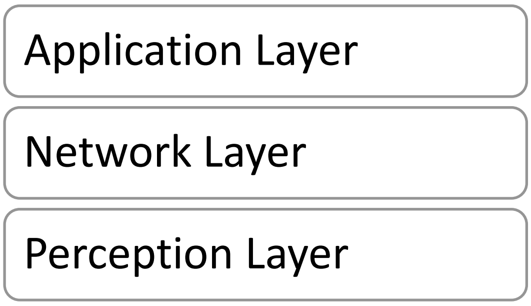

Figure 4.1: 3-layer architecture of the Internet of Things

Adapted from Wu et al. (2010)

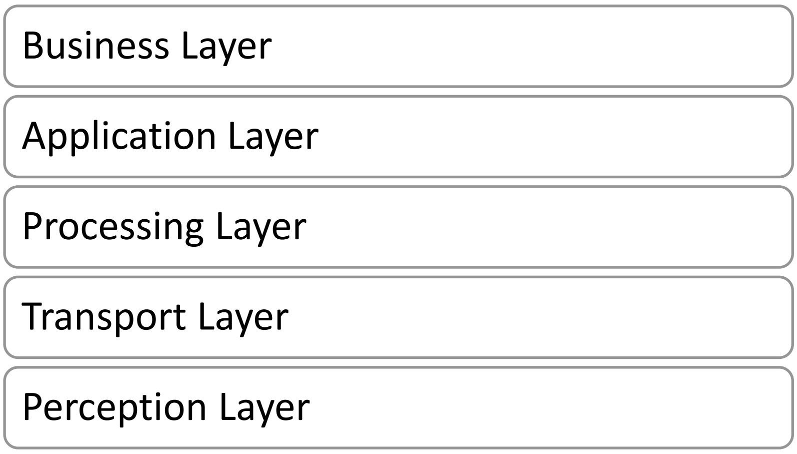

Figure 4.2: 5-layer architecture of the Internet of Things

Adapted from Wu et al. (2010)

During the data analysis, the key factor for identifying that an author considers that a smart device has network access is either when network connectivity is explicitly mentioned or when an activity that requires network connectivity is addressed. For example, (Harwood, et al , 2014) states that high internet use is something common on smart devices, this is a direct statement about the utilisation of smart devices for internet access which requires network connectivity. On the other hand, Khan, et al. (2015) mentions direct wireless interfacing and full-duplex communication between devices, this statement is a bit more indirect but at the same time assumes that smart devices have network connectivity.

One of the most explicit reference to connectivity was obtained from Cheng and Mitomo (2017) which explains that what makes these devices “smart” is their wireless communication capability, which enables them to connect to the internet

4.3.3 Context-awareness

Prior to smart devices reaching their current level of autonomy, there has been a well-established research around the definition of context and context-awareness. Brown (1996) defined context as the elements of the user’s environment that the user’s computer knows about. Ward *et al.* (1997) sees context as the state of the application’ surroundings. Dey and Abowd (1999) provided the following definition of context:

> *“Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves (Dey and Abowd, 1999)”.*

Despite the lack of IoT paradigm or smart devices by the time this definition was created, it still remains valid, therefore, this study follows Dey and Abowd (1999) theory and definition of context.

There are certain types of context to be considered. Dey and Abowd (1999) presents them as location, identity, activity and time. These context types answer to the questions of who, what, when and where, as well as acting as primary indices for second tier of contextual information. The information indexed to these primary indices is on a second level and is attached to the primary context types. For example, an object's locations can be obtained by using the object's network ID, or a forecasted weather can be related to a specific location and time.

Terms as adaptive, reactive, responsive or context-sensitive were used to describe context-aware computing. Pascoe *et al.,* (1998) defined context-aware computing as the skill of computing devices to detect, sense, interpret and respond to characteristics of a user's environment.

This user-centric definition is not applicable in an IoT environment where devices are expected to work autonomously. For this case Dey and Abowd (1999) provide an even more user-centric definition which defines a system as context-aware if it utilises context to provide relevant data to the user, where relevancy depends on the user's task.

For this research, it was necessary to find a non-user-centric definition of context-awareness. That is what the definitions provided by Salber *et al.* (1998) and Fickas *et al.* (1997). The definitions of Salber *et al.* (1998) presents context-awareness as the ability to provide maximum flexibility of a computational service based on real-time sensing of context. Similarly, Fickas *et al.* (1997) defines context-awareness as applications that monitor changes in the environment and adapt their operation to predefined or user-defined guidelines.

The main idea behind context-awareness is the ability of smart devices to perceive information from the environment through sensors such as camera, accelerometer, microphone and Global Positioning System (GPS). The information gathered through sensors can then be utilised to make autonomous decisions or to provide direct assistance to the user.

This is shown again in the 3-layer and 5-layer architecture discussed by Wu *et al.,* (2010), where the perception layer oversees the identification of objects and gathering information. This layer includes 2-D bar code labels and readers, RFID tags, cameras, GPS, sensors terminals, and sensor network. Within the paradigm of the IoT smart devices must have the capability to capture data from the environment for posterior transmission to the network.

The analysis was oriented to detect any mention of the utilisation of sensors with either “smart devices” or “mobile devices” keywords. Godwin et al. (2013) and Zhang et al. (2013) mentioned the utilisation of smart devices for photography or video recording, whereas Husnjak, Perakovic and Jovovic (2014) addressed the implementation of smart devices for human voice recognition.

The literature obtained from the keyword “mobile device” mentions the utilisation of GPS, accelerometer, microphone and camera. Furthmüller and Waldhorst (2012) explained that mobile devices offer a set of resources in which we find sensors like GPS and accelerometer. Maryn, et al. (2017) mentioned various built-in sensors carried by mobile devices such as a microphone, camera, GPS, accelerometer and light sensor.

4.3.4 User-interaction

The literature suggest that smart devices are designed to interact with users, whether it is a smartphone or smart bracelet, there is certain level of interaction with a user in which the device either collects or provide data to the user. More specifically, Kortuem *et al.* (2009) explains that smart objects carry application logic that let them make sense to their context and interact with human users. Furthermore, Streitz *et al.* (2005) discussed two approaches to implement of smart devices, namely, system-oriented and people-oriented. On a system-oriented scenario, smart devices are more autonomous making their own decisions, based on previously collected data. In a people-oriented scenario, smart devices help people make smarter, faster, more mature and more responsible actions.

Some part of the literature denotes an implicit direct interaction between smart devices and users, for example, Harwood *et al.* (2014) explained that a smart device allows users to ubiquitously conduct activities such as gaming, internet-browsing, texting, emailing, social networking and phone calls, all these activities are specifically designed for a user. In this study the main criteria for the identification of interaction with users is the mention of consumer, user, or any activity which requires a person.

It should also be noted that the IoT application layer covers among other elements user interaction (Patel and Patel, 2016). Nevertheless, although the IoT architecture encompasses user interaction, this does not include every particular device participating in the network. Furthermore, despite the inclination of smart devices being used by users, Stojkoska and Trivodaliev (2017) states that smart devices are the objects presents in the IoT. In addition, Miller (2015) establishes that the IoT is all about the interconnection of devices, to the point where some devices might never interact directly with users, whereas instead they interact with other devices. Considering the theory behind the IoT this study does not consider user-interaction as a key feature for a device to become “Smart”.

4.3.5 Mobility – Portability

The aspect of mobility and portability was found specifically for the keyword “mobile device”. Some authors refer to portability or mobility as one of the main advantages of mobile devices. As per Moreira et *al.*, (2016), portability is a key aspect of interest for practitioners in the field of education for mobile learning applications. Also, Sattineni and Schmidt (2015) mentioned how big companies like Apple and Microsoft have designed tablets to handle and process everything a normal full-size computer can along with the bonus of mobility.

Although mobility is very characteristic feature of Smartphones, tablets and smart watches, this feature does not apply to every smart device. One example is a Smart board, a board which is not mobile but is can be considered a smart device. Malkawi (2017) presents a smart board as an electronic white board connected to a computer and data show which can be used for distinct users as a typical white board as well as to open applications, navigate the web, use drawing tools, visualising text, images, audio, video and creating virtual forms or shapes.

The definition of Smart devices goes beyond Smartphones and tablets, the paradigm of IoT says that anything can be connected and smart which means that objects with low mobility should also be included into this group. For this reason, mobility is not considered as a key feature for a device to become Smart.

4.4 Discussion: What is a Smart device?

The key features found in smart devices through the review of the literature have been grouped into three main categories namely, context-awareness, device connectivity and autonomy. The literature also suggests “user interaction” and “mobility-portability” as key features to consider, but at the same time the theory behind the IoT establishes that this paradigm is about things interacting with other things.

Most of the authors when referring to “mobile devices” envision smartphones, tablets and wearables, by doing so they are addressing the same devices that other authors call “smart devices”. This investigation chooses not to include the feature of mobility to the concept of smart device hence it would then discard all devices which comply with the main categories but are not mobile. Instead, the term mobile smart device can be used.

Considering the main features of smart devices, this investigation proposes the following definition:

A smart device is a context-aware electronic device capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange.

This concept encompasses a dynamic but finite number of devices which can integrate in a network and participate in the paradigm of the IoT. section 4.1 describes other terms which have been added to the term “smart device” to describe specific features of these devices. Such terms can be: metering, wearable, hand-held, etc. Consequently, we can refer to smart devices which interact with users by using the term “smart wearable device” or “smart hand-held device”. Nevertheless, Smart device is proposed by this study as the core term to be used for the devices present in the IoT.

4.5 Summary

This chapter presented and discussed a conceptualisation of the term “smart device” within the paradigm of the IoT. The IoT is a key player in the fourth industrial revolution known as Industry 4.0. This new revolution across industries aims at introducing a new level of organisation and control within the current industry, thus taking the last industrial revolution to a new level of efficiency. Since smart devices are considered as the key objects or devices within the network of the IoT, a clear conceptualisation was necessary and yet to be done.

The terminology used in the literature included a wide range of terms for addressing the same devices. Some of the terms found in the literature are: smart wearable device, smart metering device, mobile smart device, mobile computing device, mobile hand-held device, mobile IT device, etc. The key features that the literature allocates to such devices were grouped in the following terms: Autonomy, connectivity, context-awareness, User-interaction and mobility. Ultimate smart device was defined as context-aware electronic device capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange.

This chapter has addressed the first research objective of the study which is to establish a clear definition of the concept “smart device”. Also, the first research question of the study has been addressed. The following chapter describes the utilisation of smart devices in the construction industry.

Chapter 5: Adoption of smart devices in the construction sector

5.1 Introduction

This chapter discusses the adoption of smart devices in the construction industry of the United Kingdom (UK) and the Dominican Republic (DR). This study considers adoption as a process by which an entire organisation embraces a new solution, including it into its workflow and becoming more effective as the result. It is a carefully selected word as it is not the same as using the words “implementation”, “utilisation” or “Use”. If this research would refer to the “implementation” of smart devices, we would be addressing the process of installing and configuring such devices as well as the process of staff training. This chapter intends to address is the level of adoption of smart devices in the construction industry. This includes the typical smart devices used in the industry, the general apps user behaviour and the areas of implementation of smart devices.

The findings presented in this chapter emerged from the review and analysis of the literature as well as the content analysis of semi-structured interviews. Thirty-nine (39) professionals from the Construction sector were interviewed. Subsequently, thematic analysis was used for the generation of themes. The literature showed strong evidence of typical smart devices used in the construction sector and apps user behaviour by countries.

This chapter is structured as follows: First, Section 5.2 presents the typical smart devices used in the construction industry. Section 5.3 shows the general App user behaviour and the distinct behaviours by countries. Section 5.4 discusses the areas of implementation of smart devices in the construction sector. Finally, Section 5.5 summarises the findings of this chapter.

5.2 Smart devices used in the construction sector

After surveying the New Zealand construction industry, Liu *et al.,* (2017) highlighted the mobile devices used by either the respondents or their companies. Table 5.1 presents these results. When this study was performed iPhone was by far the most used device in the industry, followed by iPad (another Apple product), then Android phones and tablets were the most common devices. Wearable devices are still not common in the industry, with only 1.42% of the respondents reporting to use these devices.

Table 5.1: Smart devices used in New Zealand construction industry

Adapted from Liu et al. (2017)

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%

The study performed by Liu *et al.,* (2017) focuses on mobile devices. Chapter 5 presents a conceptualisation of smart devices which describe the concept of smart device in this study. For this study, all the devices defined by Liu *et al.,* (2017) as mobile device, also fix the description of smart device presented in Chapter 5. They also have a valuable aspect of portability which make them definitely mobile, therefore, they could be considered as mobile smart devices.

The devices presented in Table 5.1 can be summarised as smartphones, tablets and wearable devices. This study chooses to exclude RFID tags from the categorisation presented by Liu *et al.,* (2017) because RFID can be considered as a technology associated to smart devices and the IoT, rather than a smart device itself.

The analysis of the semi-structured interviews performed in the data collection stage described in Chapter 3 revealed additional information which contributes to the existing body of knowledge of the construction industry. As shown in Table 5.2 five additional categories are added to the existing three categories previously discussed, namely, unmanned devices, smart boards, sonar and lasers equipment, GPS + Existing equipment, and security cameras.

Table 5.2: Smart devices used in the Dominican Republic (DR) and United Kingdom (UK) construction sector

Smart devices	Response percentage DR (out of 25 interviewees)	Response percentage UK (from 14 interviewees)	Total response count (from 39 interviewees)	Total response percentage
Smartphones	84.0%	100.0%	35	89.7%
Tablets	16.0%	57.1%	12	30.8%
Wearable devices	0.0%	14.3%	2	5.1%
Unmanned devices	8.0%	21.4%	5	12.8%
Smart boards	4.0%	7.1%	2	5.1%
Sonar surface	0.0%	7.1%	1	2.6%
GPS + Equipment	4.0%	0.0%	1	2.6%
Security cameras	4.0%	0.0%	1	2.6%

Interviewee UK-09 highlighted the use of non-aerial Unmanned device for supervision of places which are not either hazardous or of difficult access for human:

"We also have devices which you can put in calvers and it is like a little car with a camera that goes through the calver" (Interviewee UK-09 – Architect).

For this reason, we are purposely considering Unmanned devices for any terrain, whether it is aquatic, ground or aerial device. Unmanned Aerial Devices (AED) also, referred as drones are only one dimension of the possibilities offered by robots.

Other terms presented in Table 5.2 need some clarification. Firstly, interviewees referred to smart board as the following:

"I will explain you about the smart board. You download the App which is smart CAP, so everything you are doing on that board, whoever is connected or whoever wants to share it, will see it. If you delete or add something, they cannot let you know, but if you are talking to them on the phone, they will see what you are doing, you can capture what you have done and send it as a PDF or IMAGE file. They can also invite someone else or send that document to someone else." Interviewee DR-14 – Architect

According to Interviewee DR-14 smart boards are a useful tool for sharing information on meetings. It allows everyone connected to a specific network to gain access to the drawings on the board, and subsequently, that information can be shared with others.

Interviewee UK-12 uniquely highlighted the use of sonar surface as a way to eliminate hazard, thus improving health and safety in the organisation. The interviewee has requested not to disseminate the specific utilisation of the sonar surface; therefore, a direct quote will not be included, nevertheless, what we can specify that sonar surface was used as a means of evaluating deep water conditions without sending divers into the water, consequently, enhancing health and safety.

GPS has been included in existing equipment to perform smart metering techniques, this is furtherly discussed in section 5.4.6. Security cameras have been found to be useful for security monitoring, this is furtherly discussed in section 5.4.3.

Smartphones are the most used smart devices in the construction sector, having found that 100% of the UK interviewees use smartphones in their construction organisations. In the Dominican Republic 84% of interviewees use smartphones in their daily operations. Overall 89% of all interviewees rely on smartphones as their main smart device. Following smartphones, there are tablets, and unmanned devices.

Regardless, wearables devices are considered by Liu *et al.,* (2017) in its survey to the New Zealand construction sector, they have a very low adoption both in the New Zealand and also in this study which includes the Dominican Republic and the United Kingdom construction sector. Only 1.42% of respondents use wearable devices in New Zealand (see Table 5.1), although up to 14.3% of interviewees use wearable devices in the United Kingdom. No interviewee used wearable devices in the Dominican Republic (see Table 5.2). A valid reason why wearable device such as helmets for visualisation have not been massively adopted (besides their expensive price) was expressed by interviewee UK-01:

> *"…So we have oculus rift and google cardboard they've been the two that we have tried out, but we were not convinced that that is where the key value of all of this is. I think it's a reasonable experience and that appeals to the geeks, but I am not convinced that it is a good way of communicating with everybody, it is a very isolating experience, in VR you cannot have a discussion with the person next to you about what you see, and these kind of things." – Interviewee UK-01- Computer Scientist*

5.3 Generic apps user behaviour

Just as Silverio *et al.* (2018) highlighted a major discrepancy in the literature regarding the naming convention for what this study addresses as smart devices, there is also a discrepancy as to what is referred by the term "Mobile App". According to Silverio *et al.* (2018), Mobile devices could be considered as smart devices which offer portability to their users, such as smart phones, tablets and wearables. Hence, Mobile Apps, play a crucial role in the adoption of smart devices.

Mobile app development has become a main part of an organisation's development, just as organisations usually require their own websites, they also are requiring their own apps Lim *et al.* (2015).

According to Lim *et al.,* (2015) the most popular reason for users search for an app was when they needed to know something in specific. Also, the main reason for downloading an App was to be entertained, followed by "to carry out a task". The research performed by Lim *et al.* (2015) surveyed general Apps usage, with no focus in any industry in particular. Nevertheless, it awakes curiosity that the main goal of downloading Apps from the App store is to be entertained. It should be further discussed to what point the adoption of smart devices might generate distraction at the workplace.

The profile of the user influences usage pattern of a portable smart device. For example, Yang *et al.* (2015) found necessary to categorise uses based on their data usage; considering that heavy users of mobile data accounting for a 1% of the population (For that particular investigation) contributed to 88% of all mobile data traffic. Similar to Yang *et al.* (2015), the app user behaviours explained in this section provides an understanding of various features which should be considered when implementing mobile smart devices in a project. Technology consultants should consider variables such as data usage, mobility patterns and application usage when developing a IT system for a construction organisation. Abandonment of Mobile App should also be considered by technology consultants; In this regard, Lim *et al.,* (2015) explained that the most common reason for app abandonment was lack of needing the App anymore, followed by “finding a better alternative”, and “getting bored of the app”. Lim *et al.* (2015) also established the following reasons as relevant for App abandonment: The app crashed, the app did not have the required features, the app was too slow, the app was difficult to use, the app did not work.

5.4 Areas of implementation of smart devices

Chen and Kamara (2011) used the state of the art of mobile computing present in its time to develop a framework of using mobile computing for information management on construction sites (See Figure 5.1). Nevertheless, said framework does not consider the autonomy embedded nowadays in smart devices. It divides users and construction information, show devices used in the construction site as dependent on users.

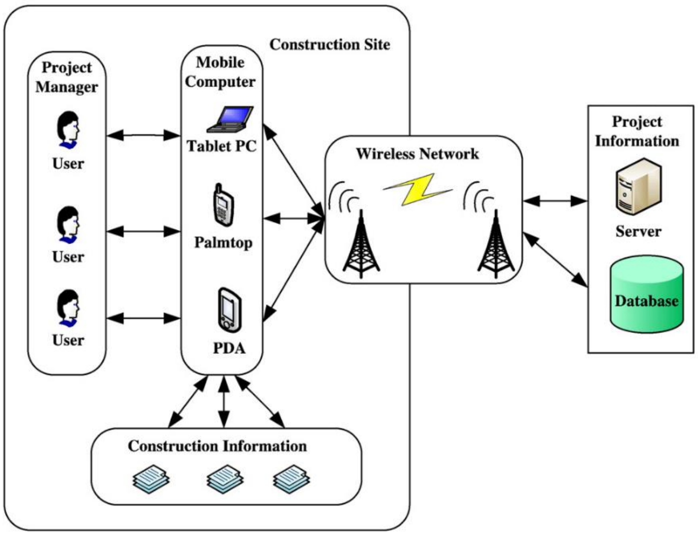

Figure 5.1: Framework for using mobile computing for information management on construction sites

Adapted from Chen and Kamara (2011)

Chapter 4 (section 4.4, page 130) defines a smart device as:

> *"A context-aware electronic device capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange."*

This definition did not exist back when Chen and Kamara (2011) developed its framework as well as the current level of mobility among smart devices did not exist either. Hence, the current utilisation of smart devices is something that requires attention and conceptualisation. Currently smart devices are a key component of the Internet of Things (IoT) which is a network that interconnects uniquely identifiable embedded computing devices (Miller, 2015).

This session discusses the utilisations given to smart devices in organisations within the construction sector. Whether smart devices are being implemented in an IoT environment or not, their main utilisations are furtherly discussed. The interviewee codes used in this chapter represent the same interviewees shown in Table 3.2and Table 3.3 (See page 114).

Table 5.3 shows the categories revealed from the analysis of the qualitative data. The utilisations shown in this table are ordered from the highest to lowest percentage of appearance. In the Dominican Republic twenty-five interviews were done, whilst in the United Kingdom fourteen interviews took place. Although the themes found by this study have the same name, a different level of implementation was found between the construction sector of the United Kingdom and the Dominican Republic. Such differences are explained in the following sections. The utilisations found in this study are: Data capturing and display; data exchange; site supervision; contextual data request; material management and smart metering.

Table 5.3: Utilisations of smart devices in the construction industry, ordered by percentage of responses

Utilisations	All interviewees %	DR - interviewees %	UK - Interviewees %
Data capturing and display	69%	72%	64%
Data exchange	46%	56%	29%
Site supvervision	28%	28%	29%
Contextual data request	21%	16%	29%
Smart metering	3%	4%	0%
Material management	5%	4%	7%

Table 5.4 shows the responses obtained from professionals in the construction industries of the Dominican Republic and the United Kingdom. The interviewee numbers assigned in theses tables are referenced throughout this chapter, they are also the same interviewee numbers shown in other chapters of this investigation.

Table 5.4: Utilisations obtained from interviewees in the Dominican Republic

Interviewee Code	Data capturing and display	Data exchange	Site supervision	Contextual data request	Smart metering	Material management
DR-01	x	x	x			
DR-02	x					
DR-03			x			x
DR-04	x	x				
DR-05	x			x		

DR-06	x			x	x	
DR-07	x	x		x		
DR-08		x				
DR-09	x	x	x			
DR-10						
DR-11						
DR-12	x	x	x			
DR-13	x	x				
DR-14	x	x	x			
DR-15	x	x				
DR-16		x				
DR-17		x	x	x		
DR-18	x					
DR-19			x			
DR-20	x	x				
DR-21	x					
DR-22	x					
DR-23	x	x				
DR-24	x	x				
DR-25	x					

Table 5.5: Utilisations of smart devices obtained from interviewees in the United Kingdom

Interviewee Code	Data capturing and display	Data exchange	Project management	Contextual data request	Material management
UK-01				x	
UK-02		x		x	
UK-03	x		x	x	
UK-04	x			x	
UK-05	x				x
UK-06		x			
UK-07	x				
UK-08	x	x	x		
UK-09	x	x			
UK-10			x		
UK-11	x				
UK-12	x				
UK-13	x				
UK-14			x		

The data obtained from the data collection is discussed below. The utilisations given to smart devices are sorted by order of relevance, based on the percentage of interviewees which mentioned each category.

5.4.1 Data capture and display

This category has the highest mentions from the interviews. Data capture and display discusses the implementation of smart devices for capturing, editing and storing information. For both the DR and UK interviewees capturing, storing and visualising information through smart devices is the most common utilisation.

The interviewees from the DR and the UK rely mostly on smartphones and tablets as the main smart devices on the jobsite. They reported to use their smart phones for photographic reports, visualising drawings onsite, taking notes and filling punch lists. Similarly, Liu *et al*. (2017) explains that construction professionals in the New Zealand construction industry utilise smart devices such as smartphones and tablets for visualising site photos and filling punch list. Some of the interviewees from the Dominican Republic stated that they use smart phones to add photos to their project reports with visual photos:

> *"Well we really use smart phones a lot, because we take photos for the reports and we need to have a registry of those pictures…" (Interviewee DR-07).*

Also,

> *"I use it to take pictures for my daily reports. I send them directly to my email and then download them to my computer and create daily reports…" (Interviewee DR-15).*

Similarly, interviewees from the United Kingdom state the usefulness of smart devices like smartphone for taking pictures and requesting useful information:

> *"…the most useful part for smart devices like smartphone or something like that is just focused on taking pictures or accessing useful information…"*
> *(Interviewee UK-06).*

In addition, other interviewees use smart phones to visualise drawings on the jobsite:

> *"…if I have a drawing and is printed and I do not want to have it on me all the time, I take a picture of the drawing, and I am with a drawing in my pocket…"*
> *(Interviewee DR-09).*

Also,

> *"I did not have to print any drawings, when I was arriving to the project if I had to modify something, I would to it in Revit, then export it to PDF and then I had the easiness to open it onsite." (Interviewee DR-18)*

Technologies related to UAV (Unmanned Aerial Vehicle), also called drone have undergone an exponential growth and have become more affordable. Future expectations of UAVs project the assembling of buildings on a fully or partially automated manner, using UAVs (Goessens *et al.*, 2018).

The implementation of UAVs has already shown to be useful for construction organisations. Interviewees explain that the main reason behind the implementation of UAVs are: Demand from the client, marketing purposes or health and safety of employees. The decision of implementing unmanned devices depends on the nature of work of the organisation and its culture and leadership.

As the following interviewees explain UAVs are facilitating tasks which otherwise would be complicated to solve by humans:

> *"… now we have one drone which just goes one buzz scans everything within the tunnel and that's it, survey done." (Interviewee UK-13)*

In summary, the utilisations grouped into this category are creation, visualisation and edition of files such as drawings, punch list, calculus sheets, construction manuals, presentations, photos and reports. Also, Drone surveying is an important sub-category to consider. As times advance more intelligent machines will be available and more task could be assigned to unmanned devices or robots depending on the cost and culture of the organisation.

5.4.2 Communication

Communication is considered as one of the key factors for solving the key challenges of the construction industry (Crotty, 2013, p.25-28). Liu *et al.* (2017) also highlights the implementation of smart devices for enhanced communication and exchanged of information among their users; presenting an Improved efficiency and accuracy of site inspections and reporting

Similarly, smart devices were reported to be used for exchanging of information through chats, emails, management apps, and calls. The exchanged media is photos, reports, drawings, construction manuals, calculus sheets and punch lists. Most of the interviewees noted that their organisations rely on cloud computing to store and share information of their projects:

> *"We send quotations through WhatsApp, chatting, sending locations, even communicating a simple message which you can forget later." (Interviewee DR-17)*

This finding corroborates a known issue in the information patterns of the construction industry. According to Box (2014) the construction industry has the highest degree of decentralisation, highest mobility and highest rate of external collaboration, also it has a high rate of digital content creation and consumption. A large amount of the exchange of information taking place in the construction industry occurs mainly through smart devices, which workers use to share any project relevant information.

5.4.3 Site supervision

Site supervision influences the performance and efficiency of construction projects (Alwi *et al.,* 1999). It is a crucial part of the execution stage of a construction project. In this context, the interviewees use smart devices for the creation of events and reminders, tracking of staff, project inspection, coordination of meetings through mobile Apps and monitoring of security cameras in real time. Smartboards are also used for information exchange among projects parties during meetings.

As the following interviewee stated, it is posible for an organisation to purchase or create an App for smartphones and tablets, which can be used to monitor the project activities:

> *"…we created an App with a dashboard behind it, so we have the plans for the total work, and then we send the activities to each one of the devices, and then we have live progress reports onsite with geotagged photos, any issues raised within the tablets." (Interviewee UK-03)*

Also, other interviewees expressed the implementation of smart phones as tools for visualisation of live feeds from security cameras:

“I even have on my smartphone the security cameras of the project. I can be at home and I connect through my smartphone and I get a view of the project.” (Interviewee DR-09)

A corroboration of this can be found on Liu *et al.* (2017) who explains the utilisation of smart devices for better timesheet management for employees and subcontractors; Improved visibility into workforce productivity, performance monitoring and evaluation; Reduced liability and risks through accurate and prompt compliance reporting.

Overall, the data shows a contribution from smart devices in distinct tasks which can be categorised as site supervision activities, because of their nature of planning, execution or control of key performance indicators. Some of these activities are security monitoring, coordination of meetings, project inspection and staff tracking.

5.4.4 Contextual data request

Contextual data gives context to a person, entity or event. A data request can be considered as contextual when the provision of information considers a context attached to the request of information to provide relevant information to the entity making the request. The interviewees stated that they use smart devices to obtain geolocation data or manuals with relevant information for the project. More specifically:

“…they use Google Earth for visualising points on the road, seeing terrain-related things, that type of things, they use the iPad for that mostly…” (Interviewee DR-06).

Also,

> *"Yes, we use GPS … We also used a device for marking points on a road project. You know what we use smartphones a lot for, for manuals; we have a manual for road signs. If we are on the jobsite we open it and we answer any query" (Interviewee DR-07).*

This indicates that based on the project type and project location the users will request they GPS to provide context to the smart device (in this case smartphone) and fetch relevant information. As interviewee 07 indicated, smartphones are being used for reading manuals on the job site. A more efficient approach could be achieved to provide a better user experience for the search of information in manuals. As interviewee DR-06 has indicated, the use of geolocation has been done on road projects. A interviewee who works in other types of projects has not indicated the need to use geo-location.

5.4.5 Material management

Materials management is the function responsible for the coordination of planning, sourcing, purchasing, moving, storing and controlling materials in an optimum manner to provide a service to the customer at a minimum cost. Material management is a complex operation which can deal with campus planning and building design for the movement of materials, or with logistics that deal with the tangible components of a supply chain.

In this study, interviewees noted that they use smartphones and tablets for exchange of material-related information. They also create inventory, material requests and follow-up of material through chat:

"…through WhatsApp, you send the amount of materials that you need, you receive in the same WhatsApp or email on your phone, and then you have control of the requested materials." (Interviewee DR-03)

Also, interviewees stated the use of barcoding for tracking of equipment and faster information retrieval:

"… in the installation of mechanical equipment, for example fan coil units, radiators or devices for managing the building which have a bar code which the customer or who is managing the building do not need the drawings but instead with a device they scan the code of that equipment and it tells them who is the manufacturer, who installed that equipment the date of replacement, cost and who to address in case of breakdown." (Interviewee UK-05)

In an effort, to automate processes of the construction industry, researchers are implementing Unmanned Aerial Vehicles (UAVs) as a tool for assembling buildings. Goessens *et al.* (2018) studies the use of UAVs to assemble masonry buildings. These research trend highlights the coming revolution of robotics in construction. With robots in the construction sector we can expect a different and more automated approach for material management. Similarly, interviewee UK-02 stated future expectations for the construction industry:

"the use of robots, that is big now. So you will find drones. Robots in pipelines work. In environments where humans cannot survive." (Interviewee UK-02)

Overall, smart devices are used to exchange material-related information between construction staff. They are also used for tracking equipment and faster information retrieval. The implementation of robots in construction projects is a new milestone, especially in hazardous environments where humans cannot survive. As a result of the steady rise in labour costs and the decreasing prices of technologies UAVs are particularly being investigated as a tool for assembling buildings faster and more efficiently.

5.4.6 Smart metering

A smart meter is considered as an electronic device that records consumption of electric energy in pre-defined intervals and communicates that information at least daily back to the utility for monitoring and billing (Federal Energy Regulatory Commission, 2008). Academic literature has the same consideration towards smart meters; for example, Wen *et al.* (2018) and Bhattacharjee *et al.* (2018) discuss smart meters in smart grids, strictly in the context of distribution and management of electricity.

In the context of this investigation, smart metering encompasses the utilisation of smart devices for gathering data in the job site. By using smart devices to collect distinct measurements, this data can be then, stored, analysed and subsequently used to improve the processes that rely on it. As stated by one of the interviewees:

> *"We are implementing some installations of hardware to the equipment, which connects to the Cloud and we can get information about how much terrain, a equipment moved, how much it was covered, how much it was cut. We are in the middle of a process of implementation so that information can be uploaded to a software that we have installed" (Interviewee DR-06)*

This means organisations have integrated smart devices into pre-existing equipment to track information and obtain metrics such as terrain compaction level and volume of terrain movement. For example, trucks initially designed to move terrain can be integrated with GPS and be used to determine the amount of terrain movement as a secondary dataset.

5.5 Summary

This chapter discusses the findings on the level of adoption of smart devices in the construction sector of the Dominican Republic and the United Kingdom. A literature review was performed to support the findings from thirty-nine semi-structured interviews.

The distinct smart devices used in the construction sector were presented. In order of most used, it is found that organisations use smartphones, tablets, Unmanned devices, wearable devices, smart boards, sonar surface, GPS integrated to existing equipment and security cameras which can be access via smartphones and tablets. Smartphones were used by 100% of the interviewees in the United Kingdom and by 84% of the interviewees in the Dominican Republic. Aerial and non-aerial unmanned vehicles were used in the construction industry of the United Kingdom, whereas, only Unmanned Aerial Vehicles were used in the Dominican Republic.

The areas of implementation of smart devices in the construction industry were classified as follow: (1) data capturing and display, (2) communication, (3) site supervision, (4) contextual data request, (5) material management, and (6) smart metering. 69% of interviewees reported using their smart devices for capturing or displaying information, followed by 46% of users reporting to use their smart devices for Communication.

It was found that by integrating sensors such as GPS in existing equipment, such equipment may become smart and provide smart metering features.

This chapter has addressed the second research objective of this study which is to explore the level of adoption of smart devices in construction projects. Also, the second and third research questions of this study have been addressed. Research question 2 is: Which smart devices are used in the construction industry? And Research question 3 is: What are the utilisations given to smart devices in construction projects? The following chapter discusses the key drivers for implementing smart devices in the construction industry.

Chapter 6: Key drivers to implement smart devices in the Construction industry

6.1 Introduction

This chapter presents the drivers and barriers to implementing smart devices in the construction sector. The results are based on qualitative data from 39 semi-structured interviews from professionals in the field of Construction of the Dominican Republic (DR) and the United Kingdom (UK). The results are based on the perception of the interviewees. The findings are discussed against the relevant literature.

The drivers obtained from the data analysis are discussed in section 6.2. Nine drivers were revealed grouped into two groups, namely, internal and external. This chapter addresses the Research Question 5 (See Chapter 1):

RQ4: "What are the drivers that incentive the implementation of smart devices?"

Finally, a summary of this chapter is presented in section 6.3, were the most suggested drivers are highlighted and an overall discussion of the chapter is presented.

6.2 Drivers for implementing smart devices in the construction industry

This section discusses the drivers to implement smart devices in organisations within the construction sector. These drivers emerged from a mixture of a critical review of the existing literature and qualitative content analysis performed after the data collection stage described in Chapter 4 (Research methodology). Interviewees were asked for the drivers to incentive or promote the implementation of smart devices in their organisations. The themes which obtained from the data analysis of the interviews were grouped into three key drivers namely, economic, managerial and corporate. Table 6.1 presents the themes which emerged from the qualitative analysis of the collected data. In order of higher to lower responses all the sub-themes obtained from the interviews can be named as follows: Productivity; Mobility; Communication; Management and procurement; Environmental protection; Corporate transparency; Competitive advantage; Health and safety; and Stakeholder satisfaction. The drivers found in the interviews were grouped into two categories, namely, internal and external. Internal drivers are the ones that directly affect the workforce of the company, whereas, external drivers affect the external environment of the organisation.

The interviewee codes used in this chapter represent the same interviewees shown in Table 3.2 and Table 3.3 (See page 114). In both UK and DR all the interviewees provided valid responses. Therefore, the percentages shown in Table 6.1 are based on the amount of the interviewees which is the same number of valid responses received.

The sub-theme or motivation most suggested by the interviewees is productivity. In this investigation, we have used the theme productivity to encompass features such as time and cost savings, as well as the efficiency of processes. The following sub-themes were only mentioned in the DR interviews: Management and procurement; Corporate transparency; Stakeholder satisfaction. Further discussion will address the possible reasons for these drivers only existing in the DR construction sector.

Table 6.1: Response counts and rates for drivers obtained from interview in the United Kingdom (UK) and the Dominican Republic (DR)

Drivers	**Total Response percentage (out of 39 responses)**	**DR response percentage (out of 25 responses)**	**UK response percentage (out of 14 responses)**	**Total response count (out of 39 responses)**	**DR Response count (out of 25 responses)**	**UK Response count (out of 14 responses)**
Internal drivers	95%	92%	100%	37	**23**	**14**
Productivity	44%	36%	57%	17	9	8
Mobility	38%	48%	21%	15	12	3
Communication	36%	48%	14%	14	12	2
Management and procurement	13%	20%	0%	5	5	0
Health and safety	5%	0%	14%	2	0	2
External drivers	28%	20%	43%	11	**5**	**6**
Environmental protection	10%	8%	14%	4	2	2
Corporate transparency	5%	8%	0%	2	2	0
Competitive advantage	5%	0%	14%	2	0	2
Stakeholder satisfaction	3%	4%	0%	1	1	0

Table 6.2 and Table 6.3 show the specific responses received by all interviewees throughout the interview process. In both DR and UK data collections all the participants provided a valid answer to the study. Also, these tables were used to confirm data saturation and ensure that further interviews were not required. According to the data saturation rules established in Chapter 4, for a theme to be accepted it should not be created in any of the last three interviews.

Table 6.2: Responses drivers DR

Interviewee code	Communication	Mobility	Productivity	Management and procurement	Environmental protection	Corporate transparency	Stakeholder satisfaction
DR-01		x					
DR-02			x				
DR-03	x		x			x	
DR-04	x		x				
DR-05	x		x				
DR-06			x				
DR-07		x					
DR-08			x				
DR-09		x		x			
DR-10	x	x					
DR-11		x					
DR-12	x						
DR-13		x	x				
DR-14	x		x				
DR-15					x		
DR-16	x	x		x	x		
DR-17		x		x		x	
DR-18		x					
DR-19	x	x	x				
DR-20				x			x
DR-21	x			x			
DR-22		x					
DR-23	x						
DR-24	x						
DR-25	x	x					
Total	12	12	9	5	2	2	1

Table 6.3: Responses drivers UK

Interviewee code	Productivity	Mobility	Communication	Competitive advantage	Environmental protection	Health and safety
UK-01			x			
UK-02	x			x		
UK-03	x			x		
UK-04	x	x				
UK-05	x					
UK-06		x				
UK-07	x					
UK-08		x				
UK-09	x				x	
UK-10	x				x	
UK-11	x					
UK-12						x
UK-13						x
UK-14			x			
Total	8	3	2	2	2	2

The following sections present and discuss the drivers obtained from the data collection and analysis. They are sorted by order of relevance, considering the percentage of interviewees that mentioned each driver.

6.2.1 Internal drivers

A set of drivers which directly affect the workforce of the company were grouped as internal drivers. This section describes the internal drivers for implementing smart devices in the construction industry. It was found that productivity (time and cost savings), mobility, communication, management and health and safety were considered as drivers that incentive the implementation of smart devices in construction projects. The following sub-sections will explain the main features of the internal drivers.

6.2.1.1 Productivity

Productivity can be defined as making use of production methodologies that do not waste inputs; increasing growth rates while decreasing the use of resources (Snyman and Smallwood, 2017). In the construction industry cost and time are common variables used for measuring productivity. For example, De soto *et al.* (2018) used cost and time as the main variables for measuring the productivity of a robotically built wall against a conventionally built wall. In this chapter, the term productivity encompasses both time and cost savings.

Productivity is the strongest driver mentioned by the interviewees. Overall, 47% of the interviewees considered productivity as a driver for using smart devices. In the DR 39% of interviewees (9 out of 25) considered productivity as a driver, whereas in the UK, 62% of interviewees (8 out of 14) considered this driver. For example, several quotes were extracted from the interviews and express the idea that interviewees from the UK and DR have of the term productivity. The following comments were extracted from the UK interviews:

- *"is cost, because there are some mistakes that will cost as the result of for example printing a lot of documents of papers all over the place, and smart devices can do that for you and it **saves time and cost**" (Interviewee UK-02 – Knowledge management specialist)*

- *"in the area of drawing, the easiness for knowing what is the state of the drawing, who produced it, and if it is up to date**, saves a lot of time** for people who are in charge to maintain Universities, educational centres, or buildings" (Interviewee UK-05 – BIM MEP technician).*
- *"The main driver is **saving money**…" (Interviewee UK-10 – Part 1 architectural assistant)*

Also, for the DR interviewees the following comments were extracted:

- *"To make the cost of construction cheaper and **decrease time**" (Interviewee DR-02 – Resident engineer)*
- *"…it **saves time**, it **saves money**…" (Interviewee DR-03 – Company director)*
- *"First is the **time you save** by not having to write things on paper or making easier information capturing, you save a lot of time…" (Interviewee DR-06 – Project manager)*
- *"In my case it **saved a lot of time**. There are many advantages and the main one is flexibility with time" (Interviewee DR-19 – Logistics coordinator)*

As can be seen, These comments include the idea of "saving time" and/or "saving cost". Both UK and DR interviewees who mentioned the decrease of construction time and cost were included in this category. In addition, other comments specifically highlight the productivity associated with the implementation of smart devices and the correct use of data:

- *"to improve production processes, improving all the productivity of construction in a general way. I believe these technologies can help us a lot and that we have not yet appropriated of them in that sense"*
  (Interviewee DR-04 – Company director)

- *"I think that with the speed and productivity, and the usefulness of data, the possibility of being able to use data is the most inspiring part"*
  (Interviewee DR-06 – Project manager)

In summary, professionals of the construction sector consider that smart devices save construction time and cost, therefore, represent an increase in productivity for construction companies.

6.2.1.2 Mobility

The term mobility refers to the capacity of a person to access data more ubiquitously, thanks to the help of portable smart devices such as a tablet or smartphone. As Sattineni and Schmidt (2015) explain smart mobile devices such as tablets can process the information that a normal full-size computer can, with the additional benefit of user mobility. The inherent portability of certain smart devices increases the user mobility of employees and the capacity for ubiquitous data access in the workplace.

Overall, 42% of the interviewees considered mobility as a driver for using smart devices. In the DR it was the second most mentioned driver with 42% of interviewees (12 out of 25) considering mobility as a driver, whereas in the UK only 23% of interviewees (3 out of 14) considered this driver. Several quotes were extracted from the interviews and express the idea that interviewees from the UK and DR have of mobility. The following comments were extracted from the UK interviews:

- *“The same information that you can access on a computer, you can access on a smartphone. So basically I think that in the future implementing this kind of use on site, even just for accessing information on the server or general knowledge it would be for sure the best solution because people going on site do not want to spend time or find a place to sit and open the computer” (Interviewee DR-06 – Project manager).*

- *“At the end you have a device, where you have together a camera, google maps, a device for calling, a device for consulting any doubt, you have everything in your pocket, and that is super important” (Interviewee UK-08 – Graduate civil engineer).*

Also, for the DR interviewees the following comments were extracted:

- *“How portable it is, I can have in my pocket all the time, and I am always with it, it is not like I have to carry a computer with me all the time, but I have it all the time with me” (Interviewee DR-09 – Resident engineer).*

- *“…with the utilisation of smart phones you save plenty of work, because you have the device handy, and you do not have to necessarily go to a computer to sit down and work. You have more flexibility to continue any other kind of work that you had at any other place. You can perform a* *work at any other place, with the same flexibility and let's say with the same quality…" (Interviewee DR-19 – Logistics coordinator).*

Both DR and UK interviewees highlight the usefulness of being able to access project files from anywhere through smart devices. As explained above smart phones bring flexibility to the workplace by allowing workers to obtain the same results from any location. In addition, particulars opinion on comfort were found from the interviewees of the DR:

- *"For me it is comfort, for example our manual is super big, and taking that manual with us would be a big burden" (Interviewee DR-07 – Project manager).*
- *"I understand that it is more comfortable, because maybe I do not have my computer on that moment, but that does not limit me. Any moment, anywhere you can check any excel template" (Interviewee DR-11 – Drawings coordinator).*

Interviewees from the DR highlighted comfort as a result of implementing smart devices. Since comfort is a by-product of the portability of certain smart devices such as smartphones, tablets and smart watches, this study has included comfort within the driver of mobility.

Another important utility of smart devices is onsite model visualisation. Interviewees have mentioned as a driver that it is more comfortable to visualise a model onsite in order to detect clashes and have a better appreciation of the project:

- *"I would feel more comfortable if on the job site I could be below of a beam with a tablet which allowed me to visualise my model. My BIM 3D model. Because one of the many good things of these models is that* *you can appreciate where are the problem and clashes. The 3D model is similar to reality, so I want to have the possibility to be in the real project next to the beam which has a tube clashing in the middle and see it in my BIM model. And see it close and understanding if someone made a mistake in the design or in the construction" (Interviewee DR-16 – BIM manager)*

This model visualisation does not necessarily includes augmented reality. Model visualisation can go from simply visualising a CAD drawing, to visualising a Building Information Model, to visualising a building elements overlaid on the construction site.

Ultimately, the driver of mobility includes distinct important features. First, it means that smart devices enable the workforce of construction companies to have ubiquitous data access, this means that construction workers can have access to data anywhere in the project, and they do not have to go to an office to fetch project information. Secondly, mobility brings more comfort to the workplace. Finally, the ability to visualise Building Models onsite, therefore having a better awareness of the project's issues.

6.2.1.3 Communication

Murray, Dainty and Moore (2007) defined communication as transmitting messages from an emitter to a receiver and successfully understanding the message. A taxonomy presented by Kreps (1989) divides communication into four levels which grow as people are added in the communication process. The lowest level is intrapersonal communication which refers to an internal process that enables individuals to process and interpret data. Then, interpersonal communication, which occurs between two people. The third level is small-group communication, which is between more than two people communicating and co-ordinating activities. Finally, there is multi-group communication, which describes the communication between different work-groups.

These levels operate within the Construction sector. For example: intrapersonal communication in the way in which a Structural engineer interprets the architectural drawings from the architectural model and visualise the superstructure of the building; interpersonal communication in the interactions between a project manager and the project's workforce; small group communication between employees of the same department; multi-group communication between a team from an organisation and distinct sub-contractor teams.

Emmit and Gorse (2006) added the concept of mass communication to the model of Kreps (1986). This level of communication refers to messages sent to large audiences, like for example between the Human resources department and all the organisation staff which might be in multiple locations around the world if the company is large enough.

This driver was generated because respondents from the DR and UK explained that enhanced communication within the organisation is one of the best attractions for deciding to implement smart devices. For example:

"The main reason for implementing technology is the quality and transfer process of the information. And being able to observe where we had errors and how we can fix them" (Interviewee DR-20).

Interviewee DR-20 explained that the quality and transfer process of information is the main attraction of this technology within the organisation. Shannon and Weaver (1948) developed a simple model of the communication process which defines the distortion between the message sent and the message delivered as noise (Figure 6.1). Following this theory, we can present smart devices as tools for reducing the noise or distortion in the process of communication.

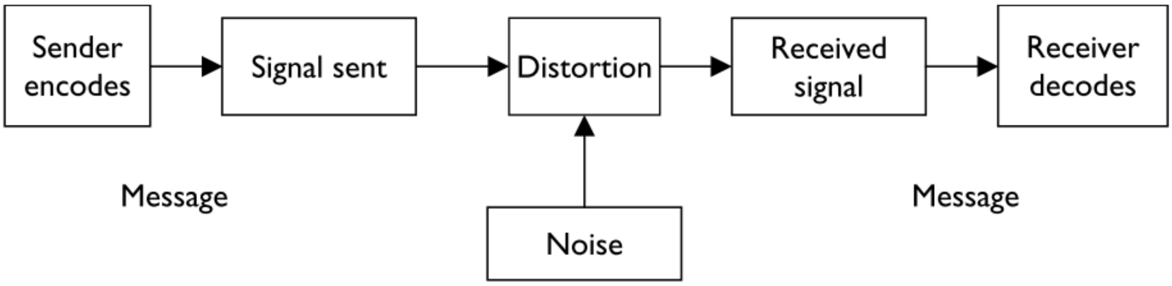

Figure 6.1: Model of the communication process
Adapted from Shannon and Weaver (1949); and Emmit and Gorse (2003)

However, a more complex and accurate version of the communication process in the construction industry can be retrieved in the literature. Figure 6.2 presents a communication process created or businesses, which adds an encoding process within the transmitter and receiver entities. Furthermore, the following question arises: Would smart devices be able to reduce the noise between the emitters and receivers of a message and also increase the encoding efficiency of the message? The answer is evident. The responses indicate that smart devices can be used to enhance communication and team collaboration:

> *"For me, it is enhancing the processes; enhancing the processes, enhancing communication, and enhancing the team collaboration" (Interviewee DR-05)*

Smart devices can provide assistant to access encrypted files, visualise drawings, videos and any other information desired by the construction organisation. They add a layer of mobility which enhances the communication techniques of the organisation.

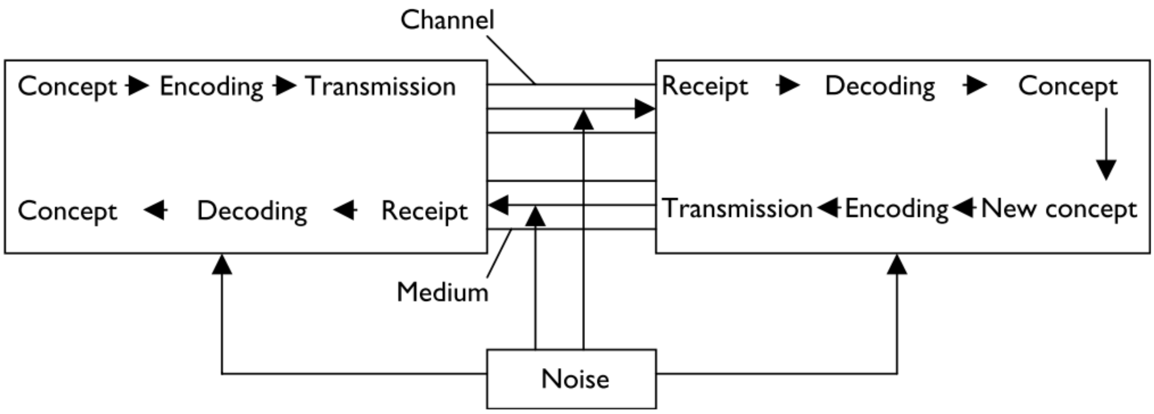

Figure 6.2: Communication process for modern businesses
Adapted from Philip Baguley (1994)

The main idea is to enhance the communication processes via the implementation of smart devices. This is an attractive feature for the organisation's decision makers. In the UK two interviewees out of fourteen total respondents suggested communication as a driver or motivation to implement smart devices. Interviewee UK-14 the following:

> *"For this company, the main driver would be to share the work around the group, I mean, I would love to see actually that we share it around, more than we currently are. It would much easier displayed in such devices" (Interviewee UK-14).*

For the organisation of interviewee UK-14 the main driver for adopting smart devices is to share the work efficiently. The devices which are used the most by employees are smartphones and tablets (See chapter 07). Nevertheless, technologies as cloud computing and Radio Frequency Identification (RFID) play an important role in automating the organisation processes and transmit information between employees.

The responses in the DR were much higher than in the UK (52% versus 15%). An assumption of what this could mean is that there are more existing communication issues in the DR construction industry, therefore, the professionals of the industry see potential in smart devices to fix this.

The literature corroborates with the findings of this study; According to Murray, Dainty and Moore (2007) Information Technology (IT) has revolutionised the ways in which people communicate within the construction industry in three main ways: (1) increasing the speed of processing information; (2) Increasing accessibility of information; and (3) Improving management information systems for more effective decision-making and control. Furthermore, the literature shows what are the cause and effects of poor communication. According to Gamil and Rahman (2018), one of the main causes of poor communication is the lack of support for advanced communication technologies. Although this is intrinsically related to smart devices and the paradigm of the Internet of Things (IoT), there are other social and organisational causes which an organisation should consider, such as, language barrier, technology malfunction, and lack of effective communication system. On the other hand, there are many negative consequences produced by poor communication, such as time overrun, cost overrun, conflict among construction parties, rework and redesign occurrence and high accident rate (Gamil and Rahman, 2018).

Ultimately, enhancing the communication processes of a construction organisation seems to have many benefits, even more considering the project-based nature of the construction industry where unfamiliar stakeholders assemble together in unique geographic, social and economic conditions to collaborate and build a project for a limited and relatively short amount of time Dainty and Moore (2007). This section has presented a concept of communication, distinct levels of communications and an adequate model for communication processes within construction organisations. It has also shown that according to the data analysis and the literature smart devices contribute with the enhancement of communication within construction organisations.

6.2.1.4 Management and procurement

Management is a recurring topic in the construction industry. Figure 6.3 shows the generic knowledge domain required by construction manager as per Edum-Fotwe and McCaffer (2000). Among the knowledge required in construction management there is: Integration and execution of project, cost and time management; quality assurance; communication planning; risks assessment; human resources; and scope planning of the project.

Figure 6.3: Generic knowledge areas of construction project managers
Adapted from Edum-Fotwe and McCaffer (2000)

Project management is considered as the practice of initiating, planning, executing, controlling, and closing the work of a team to achieve specific goals and meet specific success criteria at the specified time. Whereas procurement involves the obtention of goods and services that enable an organisation to operate in a profitable and ethical manner. This driver addresses how the construction industry perceive that smart devices contribute to their processes of project management and procurement.

Only interviews from the DR suggested management and procurement as a driver for implementing smart devices. 22% of the interviewees (5 out of 25) mentioned distinct aspects of project management as drivers for implementing smart devices in their projects. First, material management was suggested by interviewees DR-16 and DR-17:

- *"I would like to have the possibility of having a tablet or smart phones and being able to program my material requests. Being able to organise the logistics in the job site in a smart device" (Interviewee DR-16).*
- *"…to ease work with some sort of App. Like I mentioned that allows you to request materials" (Interviewee DR-17).*

In addition, Interviewee DR-21 suggested that smart devices help with the communication of big projects within large companies:

- *"I am in a very big project, so the utilisation of the smartphone helps me staying communicated at all times and allows me keep informed. To my boss that is probably in Another city and does not go every day to the project, so it keeps that interaction, so all the personnel of engineering and planning is in that city. So, there must be a constant communication the whole day between them and us" (Interviewee DR-21)*

Security management is also another important factor. As interviewee DR-16 highlights:

- *"From my smartphone wherever I am I have access to all the cameras in the project, if I want to see this one, I tap on it and there I see what is going on" (Interviewee DR-09)*

- *"linking security with technology. I would like to see an interesting proposal in that regard". (Interviewee DR-16)*

In agreeance with this finding, the literature showed that a positive perception towards the implementation of smart devices to improve management and procurement tasks. For example, Liu *et al.* (2017) Explains that shows construction workers of the New Zealand construction industry perceived the following benefits related to management tasks: (1) More efficient management of checklist and documentation; (2) Improvement of efficiency and accuracy of site inspections and reporting; (3) More efficient employee timesheet management; (4) More accurately and efficiently price and track change orders.

6.2.1.5 Health and safety

The construction sector has the worst record in the area of occupational accidents compared to other sectors of economic activity, this is because the construction sector is most susceptible to occupational accidents due to its complex and decentralised nature (Lozano-Díez *et al.*, 2019). Consequently, distinct studies have tried to reduce the sector's accident rate by accessing typical behaviour in the sector (Cloudhry, 2014), extracting evaluable par ameters from the sector's activity (Smallwood, 2015), or by integrating new systems of action in the field (Ganah and John, 2015).

Despite the relevance of Health and safety in the construction industry, this driver was only mentioned by two interviewees of the UK which represent 15% of the UK interviews and 6% of all the interviews. Interviewee UK-12 and UK-13 commented that the main concern or priority for their companies is health and safety, therefore, it was a very important driver to implement new technologies:

- *"For our company, in particular, I believe that the first thing is health and safety, so our company takes health and safety very seriously, whenever something is not safe it will not be done, so if there is a safer way of doing it that is what we'll do, and if that means that smart devices will provide it then we'll go for smart devices" (Interviewee UK-12).*

- *"The biggest concern for our company is safety, we haven't killed a worker for ten or eleven years now and that's a record, so safety is the most important. They don't really care is something is more expensive as long as it is safe, so safety goes first and then goes cost and time" (Interviewee UK-13).*

It is important to highlight that both interviewees UK-12 and UK-13 belong to Large companies. A valid assumption would be that large companies prioritise more health and safety than smaller companies.

In summary health and safety is an important factor to consider for certain companies, this study proposes the hypothesis that large companies have a higher leadership towards improving and keeping health and safety standards. Health and safety as a driver mean that even if the implementation of smart devices might incur in high implementation prices, it may still be approved by the company if it increases health and safety standards.

6.2.2 External drivers

The drivers presented in this section relate to the external environment of construction companies. These drivers are environmental protection, corporate transparency, competitive advantage and stakeholder satisfaction.

6.2.2.1 Environmental protection

The objectives of environmental protection are to conserve natural resources and the existing natural environment and, where possible, to repair damage and reverse harming trends for the environment (The Law Dictionary, 2012). A great initiative to reduce the environmental impact is to reduce paper waste in the workplace.

Both UK and DR interviewees mentioned environmental protection as a driver to implement smart devices. It is not top of the list, but it is still considered as an important factor in the construction industry. The following comments were extracted from the interviews:

- *"We design building to a high environmental standard because we are meant to care about the environment, but that doesn't really come across when you print out a small tree worth of paper every time you go to a meeting" (Interviewee UK-09).*
- *"Do you know the amount of paper that we need to print on the job site? And that becomes garbage most of the times. And in other places like us who are more organised, is still a problem because you need to have one box in the project with lot of printed drawings, up to date and out of date, which at the end of the project that is huge amount of paper. For an environmental reason it would be very interesting the migration to a smart world" (Interviewee DR-16)*

According to the interviewees, smart devices allow visualisation of documents such as drawings and spreadsheets. This allows the construction industry to become more digital. The digitalisation of the construction industry reduces the use of paper, it is this what professionals of the industry perceive as a driver for implementing smart devices, particularly, devices which allow drawing visualisation. The literature corroborates the intention of the industry of reducing paperwork with case studies of successful reduction of paper consumption in construction companies through the implementation of tablets and other smart devices. One example is shown in Coddington (2012), where a company went fully paperless from beginning to the end of a project. Also, Hogan, Ghanem and El-Gafy (2015) presented a successful case study where the company created paperless processes for construction projects by using tablets loaded with drawings sets stored in the cloud.

6.2.2.2 Corporate transparency

Throughout the literature, there are various definitions of transparency. Larsson *et al*. (1998) define it as openness toward partners, whereas Potosky (2008) defines it as the degree to which a communication medium facilitates a clear communication exchange. Ultimately, Schnackenberg and Tomlinson (2016) define transparency as the perceived quality of intentionally shared information from a sender. In this context corporate transparency refers to the quality of transfer of intentionally shared information within a corporate environment.

Interviewee DR-03 and DR-17 commented on corporate transparency as a driver for implementing smart devices. The following comments were extracted from the interviews:

- *"It is a solution for legal problems, I have everything saved, during the whole project" (Interviewee DR-03).*

- *"On WhatsApp, we have a group and we send photos through the group. And like I mentioned the department of Quality assurance has a tablet with an App with all the templates for quality surveys. That makes the process easier and more transparent" (Interviewee DR-17)*

According to these comments, smartphones and tablets allow file sharing between employees. This is considered by the interviewees as a way to increase the transparency of the company. The literature on corporate transparency offers guidance on how this seems to be correct.

Following the guidelines of Schnackenberg and Tomlinson (2016) corporate transparency is considered as a function of disclosure, clarity and accuracy. Disclosure is defined as the perception that relevant information is received in a timely manner, therefore this variable is considered to increase as stakeholders perceive information as more relevant and timelier. Clarity is defined as the perceived level of lucidity and comprehensibility of information received from a sender; it increases as stakeholders perceive information to be more understandable. Finally, accuracy is defined as the perception that information is correct to the extent possible given the relationship between receiver and sender; it increases as stakeholders perceive information as more reliable.

According to Schnackenberg and Tomlinson (2016), organisations can increase their level of disclosure through the use of open information systems. Therefore, by sharing information through the cloud and accessing it via smart devices a company increases the level of disclosure, and consequently its corporate transparency. Smart devices also offer a means to track historically all the communication between stakeholder, this can be very useful when stakeholders have disagreements to call back on previous decisions and conversations.

In summary, corporate transparency addresses the accuracy, clarity and level of disclosure of the communication and information exchange between the stakeholders of a project. This section explains that interviewees in the DR find useful smart devices to increase corporate transparency in their corporate processes.

6.2.2.3 Competitive advantage

Competitive advantage represents a successful survival and growth of a company in the market. According to Jolly *et al*. (2016), a construction firm which is successful in innovation could increase its chances of survival and growth.

Interviewee UK-02 and UK-03 identified competitive advantage as a motivation or driver for implementing smart devices. According to interviewee UK-02:

> *"For many companies, it would be competition, you have to be able to stay in business, so if your competitors are using particular gadgets or smart devices, then they become more a competitor advantage…" (Interviewee UK-02).*

According to this comment, some companies implement smart devices to catch up with other companies. Once various companies start implementing new technology, others might feel pressure to follow a tendency. However, no interviewee in the DR mentioned competitive advantage, therefore, we can consider that is a particularity of the UK market.

Similarly, the literature highlights the effects of implementing new technology in the competitive advantage of the organisation. According to Jolly *et al*. (2016) effective implementation of new technology can provide important competitive advantages for construction companies.

6.2.2.4 Stakeholder satisfaction

This study considers stakeholder satisfaction as the achievement of stakeholders' pre-project expectations in the actual performance of each project stage (Li, NG and Skitmore, 2012). According to Yang *et al.* (2011), stakeholder satisfaction can be used as a criterion for measuring project success in addition to more traditional measurements such as time, cost and quality.

Only two interviewees from the DR identified customer satisfaction as a driver for implementing smart devices in their projects. According to Interviewee DR-20 construction companies are applying technology to satisfy their clients:

> *"In the case of construction companies are applying technology just to provide more confidence to their clients" (Interviewee DR-20)*

Interviewee DR-20 suggest that smart devices enhance the relationship between the client and the construction company, narrowing down all the stakeholders benefited from the implementation of smart devices to only the client. The literature provides several critical factors to measure or appreciate stakeholder satisfaction. Ahmed and Kangari (1995) presented six factors for achieving client satisfaction in the construction sector, namely, time, cost, quality, client orientation, communication skills and response to complaints. As can be seen, time and cost are part of the driver "productivity" and communication skills and response to complaints are included in the driver "communication". We can infer that by increasing productivity and communication between the stakeholders of the projects, stakeholder satisfaction will be achieved. Other studies such as Leung *et al*. (2004) highlight that stakeholder satisfaction is achieved by management mechanisms such as communication, participation and commitment, rather than project goals like time, cost and quality.

Ultimately, the implementation of smart devices comes along with higher productivity and improved communication between stakeholders, this seems to improve the stakeholders' satisfaction. Although interviewees focused on client satisfaction, the literature encompasses all stakeholders.

6.3 Summary

This chapter presents the drivers for implementing smart devices suggested by professionals of the construction industries of the UK and the DR. The drivers were obtained from a qualitative data collection and analysis (see Chapter 3 – Research methodology). In total 39 semi-structured interviews were conducted to professionals in the field of Construction of the UK and the DR.

The drivers described in this chapter were (in order of relevance) productivity, mobility, communication, management and procurement, environmental protection, corporate transparency, competitive advantage, health and safety, and stakeholder satisfaction. Productivity was the most mentioned driver by the interviewees. 47% of interviewees considered productivity as a driver for them implementing smart devices in construction projects. As explained in section 6.2.1.1 the term productivity encompasses both time and cost savings.

Mobility was the second most relevant driver found through the interviews. The interviewees highlight the usefulness of smart devices for accessing data ubiquitously and being able to visualise the project's information anywhere.

According to the interviewees and the literature, smart devices can revolutionise the way construction personnel exchange information. Therefore, communication is a very important driver which is linked to mobility, corporate transparency and stakeholder satisfaction.

Environmental protection was also found as a driver in both the UK and DR. It appears that the most noticeable contribution of smart devices to environment protection is reducing the paperwork in projects. The literature showed several examples of companies which implemented paperless projects (Coddington, 2012; Hogan *et al.*, 2015).

The drivers with least comments were corporate transparency, competitive advantage, health and safety and stakeholder satisfaction. Despite the low amount of mentioned, (less than 10% of the interviewees) these drivers offer a valuable insight into the possibilities and main motivation behind the implementation of smart devices in the Construction industry.

This chapter has addressed the third research objective of this study which is to investigate the drivers for implementing smart devices in the construction sector. Also, the fourth research questions of this study have been addressed. The following chapter discusses the key challenges for implementing smart devices in the construction industry.

Chapter 7: Key challenges to implement smart devices in the construction industry

7.1 Introduction

This chapter presents the challenges to implementing smart devices in the construction sector. The results are based on qualitative data from 39 semi-structured interviews from professionals in the field of Construction of the Dominican Republic (DR) and the United Kingdom (UK). The results are based on the perception of the participated interviewees. The findings are discussed against the relevant literature.

The challenges obtained from the data analysis are discussed in section 7.2. The challenges found in this study were grouped into the following categories: Economic, cultural and technologic. This chapter addresses the Research Question 5 (See Chapter 1).

RQ5: What are the challenges that the construction industry faces for implementing smart devices?

Finally, a summary of this chapter is presented in section 1.4, were the most suggested drivers and challenges are highlighted and the overall of the chapter is presented.

7.2 Challenges for implementing smart devices in the construction industry

This section discusses the challenges in implementing smart devices in construction companies. These challenges emerged as a result of a qualitative data collection and analysis described in Chapter 3 (Research methodology). 39 semi-structured interviews were performed to professionals of the Construction industry in the UK and DR. The interviewees were asked about the challenges for implementing smart devices in their companies and projects. The themes which arose from the interviews were grouped into three key challenges namely, economic, cultural and technological. Table 7.1 presents the three key challenges which emerged from the qualitative data analysis of the collected data.

The interviewee codes used in this chapter represent the same interviewees shown in Table 3.2 and Table 3.3 (See page 114). Some interviewees when asked about the challenges for implementation addressed directly the Critical Success Factors for implementing smart devices. Therefore, In the UK from 14 interviewees, 13 provided valid answers. In the DR from 25 interviewees, 23 provided valid answers. In total 36 interviewees provided valid answers. The percentage shown in Table 7.1 are based on the number of valid responses.

Economic challenges had the highest rate of response, with 64% of the interviewee (23 out of 36). Cultural challenges were proposed by 58% of interviewees (21 out of 36). Finally, Technological challenges were mentioned by 50% of interviewees (18 out of 36).

Table 7.1: Response count and percentage challenges

Challenges	Total Response percentage (out of 36 responses)	DR response percentage (out of 23 responses)	UK response percentage (out of 13 responses)	Total response count (out of 36 responses)	DR Response count (out of 23 responses)	UK Response count (out of 13 responses)
Economic challenges	64%	65%	62%	23	**15**	**8**
Cultural challenges	58%	57%	62%	21	**13**	**8**
Technological challenges	50%	52%	46%	18	**12**	**6**

Both DR and UK data collection provided valid answers to the study. Also, these tables were used to confirm data saturation and ensure that further interviews were not further required. According to the data saturation rules established in Chapter 4, if any new theme is created during the last three interviews then further interviews would be required.

The following section explains the challenges obtained from the data collection and analysis. They are sorted by order of relevance, considering the percentage of interviewees that mentioned each challenge.

7.2.1 Economic challenges

Economic challenges are a recurring topic for Information Technology (IT) investment. As Love and Irani (2001) states, the evaluation of IT investments requires a significant amount of investment, which should consider the indirect (organisational and human) costs. IT costing requires adequate modern cost accounting systems which factors of social, economic and technological character.

Cost is a key aspect mentioned by the interviewees. Various quotes from the interviews for showing and insight into the perspective of the industry. Firstly, the following comments were extracted from the UK interviews:

- *"The main barrier is cost. Cost and changing people's mind" (Interviewee UK-04)*
- *"I think the main challenge is the money. I think my current supervisors are not willing to actually pay for it…" (Interviewee UK-14).*

Secondly, the following comments were extracted from the DR interviews:

- *"Well in this country which is a third world country, we do not develop these technologies, so they are expensive. So, it would be cost basically. Cost would be the main issue" (Interviewee DR-14).*

- *"The other problem is the cost, because that could be expensive, I see it as a challenge not an impossibility" (Interviewee DR-16)*

According to interviewees the economic aspects of smart devices is the main challenge for their implementation in construction projects. Similarly, King and Perry (2017) states that upfront purchase cost is a leading challenge for integrating smart building technologies. Also, Lawrence *et al.* (2016) consider operating costs as a critical challenge for integrating smart building technologies.

In addition to the cost of implementation, company size plays a crucial role as part of the economic challenge. Two interviewees in the DR and one in the UK h

> *"In relation to the side of the company it's not actually that bigger cost, but because there it's a small company that has never done anything like that before it seems a bit more risky to spend the money in something like that…" (Interviewee UK-09)*

Also,

> *"…a project of certain magnitude maybe can absorb a cost like this but for a smaller project, we would need to see if really this kind of tool could be cost effective." (Interviewee DR-04)*

7.2.2 Cultural challenges

This section describes the cultural challenges found through data collection, the organisational culture of the company plays a key role as a component of the cultural challenge. Prior to describing said challenge, it is important to describe the context within the literature around culture and cultural features.

Many definitions of culture can be found in the literature. Trompennars (1996) defines national culture across various dimensions such as universalism versus particularism, specificity versus diffuseness, internal versus external control, affective versus relationships and achievement versus ascription. Triandis (1994) identifies four cultural dimensions that apply to all cultures, namely, cultural tightness, cultural complexity, individualism and collectivism. Ultimately Hofstede provided one of the most widely accepted of culture Hofstede (2001); Hofstede, Hofstede and Minkov (2005) define culture as “the collective programming of the mind that distinguishing the members of a group or category of people from others”.

The distinct cultural dimensions are very important to compare the implementation of Information Technology (IT) on a country level. For example, the variable of power distance has shown a strong correlation with the successful implementation of distinct IT systems across the literature; Power distance provides a useful cultural variable for forecasting the effectiveness of implementation strategies that relies on users confronting implementers Griffith (1998). In a culture of high power-distance, the individual with the power feels more far, detached and “superiors” from a general point of view; whereas a low power distance means that a powerful member of the organisation is not perceived as a distant person by its subordinates, who feel closer and more befriended with their superiors.

Hasan and Ditsa (1999) found that successful adoption of IT is more likely to occur in low power distance cultures. This is because in low power distance cultures, the employees, students or people who are given a new IT system are more likely to communicate any complaints or malfunctions to the implementer. Also, students in a low power distance country are more likely to be innovative and trusting of technology Srite (1999).

These examples show the value of cultural dimensions. For this investigation is important to distinguish the distinct cultural features that affect the successful implementation of smart devices. Therefore, this section highlights the cultural challenges found by analysing the DR and UK construction industries, providing an insight in the similarities and differences between these two countries.

Interviewees found that UK and the DR found lack of leadership as a challenge for implementing smart devices in their projects. According to the interviewees a lack of leadership means that the decision makers of the company will be reluctant to implement an unknown IT solution in order to avoid risks. The following comments were extracted from the interviews:

- *"Another thing could be leadership, sometimes you need the leadership to go into the use of smart devices because you might introduce it, but if the strategy is not driven from the top-down of the company it might be a bit of challenge." (Interviewee UK-02)*
- *"Well, my boss is the sub-contractor and he has a boss above him, so it depends on both of them for having money for buying a smartphone or an App for improving the development of the project. So it just not depend on my boss but also his boss who is hiring him." (Interviewee DR-22)*

Leadership was also mentioned as a Critical Success Factor for implementing smart devices (See chapter 9). In both UK and DR construction industries leadership is a fundamental factor to achieve successful adoption of smart devices. Liu *et al.* (2017) highlights the following benefits from increasing an organisation's leadership: efficient management of documentation, improved efficiency and accuracy of site inspections and reporting, better client relationship management and satisfaction, reduced liability and risks through accurate compliance reporting.

The level of leadership in the organisation will define how likely managers are to embrace change. However, it is also important to analyse how likely are employees to adopt new technologies as instructed. By answering these questions construction organisations can draw a better understanding of the staff culture. Companies with a low embracing culture towards IoT and smart devices should thread carefully toward this implementation, measuring the benefits and the perception of employees towards new smart devices being implemented. On the other hand, companies with a high embracing culture towards the adoption of new smart devices, are recommended to aim for a deeper adoption of smart devices. The provide answer to these questions this chapter also analyses the organisational culture and training and development as part of the cultural challenges of the construction industry.

Organisational culture influences the way people set professional goals in the workplace, it affects the way in which people consciously and subconsciously think, ultimately defining the way how people perform tasks and administer resources to achieve them (Lok and Crawford, 2004).

It was found that 19% of interviewees (7 out of 36) proposed organisational culture as a challenge to successfully implement smart devices. The following comments were extracted from the interviewees:

> *"Top one is resistance to change, so we are in a project-based industry so people, great professionals, responsible people, they are more focus on delivering the project, and they have really tight deadlines and budgets, so when you try to sell them something new, they are not really interested because that is not their main focus." (Interviewee UK-03)*

Also,

> *"…I think that the main challenge is changing the way of doing things, that is creating a consciousness that says that things can be done better and that the people are willing to change." (Interviewee DR-05)*

As mentioned by interviewee DR-13 the mentality of the people in the DR influences the adoption of new technology. Similarly, other studies have found that different mentalities across countries alter the adoption or learning process of a new IT systems (Arpaci, 2015; Hasan and Ditsa, 1999; and Hofstede, Hofstede and Minkov 2010).

Staff training is a Critical Success factor mentioned by interviewees in Chapter 9. It is of relevance at the time of implementing smart devices in construction projects because allows a construction organisation to explode all the benefits from the implemented devices. A complex IoT system might require some employees to gather data in a particular manner in order to other employees be able to access such information in the future. The wrong collection of data might make the whole system underperform or behave incorrectly. It is necessary to draw a realistic understanding of the capabilities of the employees to adopt new technologies.

Training and development had 19% of responses (7 out of 36), 15% from the interviewees of the UK (2 out of 13) and 22% from the interviewees of the DR (5 out of 23).

> *"In the office there is only like two or three people in their twenties and everyone else is late forties, when people are in that age, they are not too keen to get involved in new technology, you are lacking in people's relevant experience or know how to actually implement things like that." (Interviewee UK-09)*

Also,

> *"I would say that maybe the training of the personnel. It will be more difficult for someone who is not prepared to see those things yet to understand what you are explaining." (Interviewee DR-18)*

A great part of this challenge is the lack of training and technology awareness that construction personnel can have. For example, interviewee DR-16 commented:

> *"Another important challenge is making aware to the professionals of the sector of engineering. And I am not just narrowing it down to construction, I encompass engineering because this goes from the designer to the executioner. We have to make them aware of the positive impact that technology can have in construction. Explaining in a clear way, you have these benefits, and which are the challenges…" (Interviewee DR-16).*

In summary, Training and development of employees seem to foster an environment where professionals of the industry will be more prompt to adopt new technology.

Interviews revealed that the distraction of employees is a concern or challenge considered at the time of implementing smart devices. According to interviewees DR-07 and DR-13:

- *"Well, I think that there are people who use facebook and Instagram a lot while working, so mobile can also be a bit distracting…" (Interviewee DR-07).*
- *"There are other companies that may think that if they are providing a technologic device that will not make your job easier and instead will distract you." (Interviewee DR-13).*

It seems that social media can largely disrupt the workflow of employees. The distraction of employees can be easily limited to smartphones, and maybe tablets. Similarly, in a study performed by Sattineni and Schmidt (2015) it was found that workers were distracted by mobile devices and that this could lead to safety issues.

Project location was an issue only for the DR construction industry. Interviewees highlighted the following:

"In Dominican Republic one of the difficulties that you may have is that delinquent comes and steal it, because they can easily take it or kill you. Right now there is not a lot of security." (Interviewee DR-11)

Also,

"…the case is that for implementing technology at the jobsite there is a little problem and that is the location. If you are somewhere where you do not have Internet, you do not have access to electricity. Which is something that happens in a project, you start a project in a zone which does not even has electricity or

there is not Internet signal or access to other resources. Then it results difficult to work without Internet or working under rain." (Interviewee DR-20)

Interviewees DR-11 highlighted that in certain locations it is too dangerous and smart devices can be stolen. This is an important contribution to knowledge which tells us that we should consider the social context surrounding the project location prior to the implementation of smart devices. Interviewee DR-20 highlighted that in certain locations there is no internet access; A lack of Internet access should be categorised as a technological challenge. Next section will describe the technological challenges for implementing smart devices.

7.2.3 Technological challenges

Three challenges addresses aspects such as hardware constraints, Internet access and usability. The following comments shows the opination of two interviewees regarding hardware constraints of smart devices:

- *"There are some technical challenges that we've come across most of which we've been able to work our way around. Sort of accuracy of GPS is one challenge. Plus or minus five meters is not good enough in an urban environment. It's ok when you're thinking about wind farms but in an urban environment, that's completely the wrong side of the building, which isn't good." (Interviewee UK-01)*
- *"Smart devices have limitations by nature. How many keys are in a smart device? There is one, nowadays they do not have any. Whereas a computer has full keyboard and a mouse. The combination of mouse and keyboard, the amount of things that you can do with those peripheral*

devices are unlimited. I imagine that working with BIM should be little complex, handling a 3D model with your hands." (Interviewee DR-16)

Overall, these interviewees complain about the lack of computing performance and lack of GPS accuracy found in smart devices when compared with standalone computers. Also, the user interface of smartphones was mentioned in contrast to standalone computers. Other interviewees commented about the battery life of their devices:

- *"That you always have to charge it for example, and the day that you do not charge it, if you are not prepared to do it with something else, then you are with nothing." (Interviewee UK-08)*
- *"Another disadvantage is battery life, if you are working with a computer then you know that it is plugged to a stable source of energy, but a smartphone can run out of charge. You can have some inconvenient like that on the job site." (Interviewee DR-19)*

According to these interviewees, the battery life of smartphones is an issue in the job site. Elazhary (2018) also commented about the challenge present in smartphones regarding battery life. Smartphones were categorised as weaker devices from the point of view of their battery life. Nevertheless, hardware specifications are always changing, therefore, more than focusing specifically on GPS accuracy and battery life, this challenge should be taken as advice on checking what are the hardware limitations at the time of implementation.

Internet access was mostly suggested in the DR. Nevertheless, in the UK it was not mentioned. This is probably due to the difference in data access between these two countries. According to the interviewees:

- *Another thing in our country would be Internet access because most of the things that you solve in smart devices are through Internet, so if you are exchanging information, you need to have Internet in your tablet. And in the job site, you do not know if your smartphone will have a signal to receive everything. (Interviewee DR-18)*

- *"…Another thing would be to improve the internet connection, making them stable and fast." (Interviewee DR-25)*

The interviewees comment on the need for a better internet connection. The technological context surrounding the project location should be considered prior to the implementation of smart devices.

Finally, usability is the last aspect to consider within the technological challenges for implementing smart devices in construction projects. The International Organisation for Standardisation defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241-11, 1998). The ISO standard presents the main features of usability as efficiency (a measure of task time), effectiveness (a measure of task completion), and satisfaction (a measure of users' experience). For this study, one interviewee in the UK and one in the DR commented the following:

- *"…sometimes platform that are not very user-friendly for the users. So people who are used to an old way of thinking do not open to the possibilities of working with those devices because they find it complicated. So that would be a disadvantage, a not user-friendly platform." (Interviewee DR-19).*

- *"So, on our company we installed Tom Toms that track your speed all the time … it helps you know where you are, but it also makes sure that you are legal. As an idea I like it, but the thing is that every time I get into my car I have to login to the system, sometimes it doesn't work, there is not signal, or sometimes I forgot my password, sometimes I have to do several stops and I can't every time I jump in my car put the code, drive, get out, jump in, put the code, drive. So, most people tend not to use it." (Interviewee UK-13)*

These comments explain the previous experience with smart devices and how a lack of efficiency, effectiveness and satisfaction in smart devices was a challenge for implementation.

7.3 Summary

This chapter has discussed the distinct challenges for implementing smart devices in the construction industry, which were found in this investigation. The challenges were grouped into three categories, namely, economic, cultural and technological. Economic challenges discusses aspects such as cost and company size; Cultural challenges addresses barriers such asthe organisational culture of the company. Technological challenges encompass hardware and technological constraints of implementing smart devices.

The cultural challenges described in this chapter were suggested by 58% of the interviewee (21 out of 36). The organisational culture influences the way people set professional goals in the workplace, it affects the way in which people consciously and subconsciously think. This was an important cultural challenge for interviewees of both countries. There is agreement with the literature and the collected data about the distraction caused by smartphones in workers.

The technological challenges were commented by 50% of interviewees (18 out of 36). They describe hardware and technological constraints such as battery life, lack of computing performance and lack of GPS accuracy. Also, poor usability and internet access were considered as technological challenges.

This chapter has addressed the fourth research objective of this study which is to investigate the challenges for implementing smart devices in the construction sector. Also, the fifth research question of this study has been addressed. The following chapter discusses the Critical Success Factors for implementing smart devices in the construction industry.

Chapter 8: Critical factors for successfully implementing smart devices in the construction sector

8.1 Introduction

This chapter presents the Critical Success Factors (CSFs) for a successful implementation of smart devices in the construction industry. The results are based on qualitative data from 39 semi-structured interviews from professionals in the field of Construction of the Dominican Republic and the United Kingdom. The results are based on the perception of the participated interviewees. The findings are discussed against the relevant literature.

The CSFs obtained from the data collection and analysis are presented and discussed in section 8.2. Six CSFs were revealed. Each of these factors is discussed. This chapter addresses the Research Question 8 (See Chapter 1) *"What are the critical success factors for implementing smart devices in the construction industry?"*. Finally, a summary of this chapter is presented in section 8.3.

8.2 CSFs for a successful adoption of smart devices in the construction industry.

For this study CSF is defined as follow:

> "Critical success factors are those few things that must go well to ensure success for a manager or an organization and, therefore, they represent those managerial or enterprise areas that must be given special and continual attention to bring about high performance.*" (Boynton et al., 1984).*

This session discusses the CSFs to embed and implement smart devices in organisations within the construction sector. These CSFs emerged from the content of the interviews. The generation of CSFs was based on a qualitative content analysis approach which produced common themes among respondents. This study addresses the most common themes considered to be relevant for the Construction industry. Interviewees were asked for the critical factors for successfully implementing Smart devices in construction projects.

Table 8.1 shows the categories revealed from the analysis of the qualitative data. The CSFs showed in this table are ordered by percentages of mentions. In the Dominican Republic twenty-five interviews took place, whereas in the United Kingdom fourteen interviews were done. Regardless, this difference in the number of interviews performed in this study, the CSFs in both countries had very similar percentages of mentions. For both countries the top five CSFs were Leadership, Staff training, culture, technology awareness and cost of implementation. Whereas the United Kingdom showed two particular success factors, namely productivity and automation of processes. Also, the Dominican Republic was the only one to mention company size as a success factor.

Table 8.1: Response counts and rates for CSFs obtained from interviews in the United Kingdom (UK) and the Dominican Republic (DR)

CSF	DR response percentage (out of 19 responses)	UK response percentage (out of 11 responses)	Total Response percentage (out of 30 responses)	DR Response count (out of 19 responses)	UK Response count (out of 11 responses)	Total response count (out of 30 responses)
Leadership	47%	45%	47%	9	5	14
Staff Training	26%	36%	30%	5	4	9
Organisational Culture	26%	27%	27%	5	3	8
Technology Awareness	21%	27%	23%	4	3	7
Cost	21%	18%	20%	4	2	6
Company size	21%	0%	13%	4	0	4
Usability	11%	9%	10%	2	1	3

Table 8.1 shows the responses obtained from professionals in the construction industries of the Dominican Republic and the United Kingdom. The interviewee codes used in this chapter represent the same interviewees shown in Table 3.2and Table 3.3 (See page 114).. Table 8.2 and Table 8.3 show the specific responses received by each individual interviewee. From the DR interviews, nineteen interviewees provided valid CSFs. Other interviewees suggested challenges to implement smart devices, which are included in Chapter 8 (Drivers and challenges to implement smart devices in the construction sector). Similarly, in the UK, eleven interviewees provided valid CSFs out of fourteen.

Table 8.2: CSFs obtained from interviewees in the Dominican Republic

Interviewee Code	Leadership	Staff Training	Culture	Technology Awareness	Cost	Company size	Usability
DR-01					X	X	
DR-02							
DR-03							
DR-04	X						
DR-05				X			
DR-06							X
DR-07							
DR-08							
DR-09	X						
DR-10							
DR-11				X			
DR-12	X			X			X
DR-13	X						
DR-14						X	
DR-15				X			
DR-16		X			X		
DR-17	X		X				
DR-18	X		X				
DR-19		X	X		X		
DR-20	X	X	X		X	X	
DR-21		X				X	
DR-22	X						
DR-23							
DR-24	X		X				
DR-25		X					

Table 8.3: CSFs obtained from interviewees in the United Kingdom

Interviewee code	Leadership	Staff Training	Culture	Technology Awareness	Cost	Usability
UK-01						
UK-02	x	x	x			
UK-03	x					
UK-04	x	x				
UK-05	x			x		
UK-06			x			x
UK-07						
UK-08					x	
UK-09		x		x		
UK-10	x	x				
UK-11						
UK-12			x			
UK-13					x	
UK-14				x		

The CSFs obtained from the data collection as discussed below. They are sorted by order of relevance, considering the percentage of interviewees that mentioned each category.

8.2.1 Leadership

Leadership was the most suggested CSF by the interviewees. In both UK and DR construction industries, leadership is a fundamental factor to achieve a successful adoption of smart devices. 47% of all respondents mentioned leadership as a CSF. The literature states that governance and leadership play a fundamental role in the enrollment of the decision makers on the ventures. Organisations with leadership towards innovation find themselves with a top management sponsorship towards the implementation of new technologic solutions (Burmeister et al., 2015).

A critical step towards the implementation of any new paradigm is convincing the decision makers of a company about the benefits of such implementation. Following the survey performed by Liu *et al.* (2017) these benefits could potentially be: more efficient management of documentation, improved efficiency and accuracy of site inspections and reporting, better client relationship management and satisfaction, reduced liability and risks through accurate and prompt compliance reporting.

As explained in the following comments, respondents advise that enrolling the decision makers into the implementation of smart devices is probably the most critical step for succeeding in this implementation:

> *"… we need to push them (decision makers) so they see the benefits they get from having more technology on the job site. Maybe they do not know that I take a picture of a drawing and I move around with my dimensioned drawing on my phone. So, Anything I need to check, I can do it." (Interviewee DR-09)*

Also:

> *"I think that it would be critical for the managers to see that those benefits are tangible. Once they see, those benefits are real and can help you on the long term; they would be more open to adapt and to invest in that technology." (Interviewee DR-13)*

One of the main steps towards increasing leadership in a construction project is adopting a collective mentality about which technology is helpful for construction projects. In this regard, one of the respondents noted that:

> *"I think that first we need to implant a collective mentality, that this technology is necessary, important and relevant." (Interviewee DR-12)*

The creation of awareness among decision makers of a company seems to be a critical point for implementing any new solution in the construction industry. Respondents suggest that a case study of a successful implementation of smart devices in a construction project will promote the implementation of any new technologic solution positively.

"… I think that we need to be able to show more cases of success, and doing it on a regional level because in our local industry we can see a case study of England or the United States and we quickly say 'well that is over there, that is another workforce, that is another technology', when we see here cases of Latin America, we believe a little more. And if we see cases of applications in the same country then we take it for granted. So, I believe that we need to make an effort to show more evidence that this works." (Interviewee DR-04)

Also,

"…Yes a case study would be ideal, a case study that ultimately shows benefits and people can see it, that if here this happens, then it could happen to them, and see the benefit of it." (Interviewee DR-13)

It is necessary to create awareness among decision makers of construction companies through the creation of knowledge which supports and validates the implementation of smart devices. As previously mentioned by respondent DR-04 and DR-13, this can be done through the development of case studies of successful implementation of smart devices in the country of implementation. A case study in Latin America has more credibility among decision-makers in the Dominican Republic since it would reflect similar socio-economic conditions. The case study should be preferably in the same country of implementation and should show the benefits and savings earned through the implementation of smart devices within a construction project as well as the main challenges for implementation. Following the theory of Nonaka et al. (1996) the creation and transfer of explicit knowledge through a case study should be structured, codified and digitised; providing documented information that can facilitate action. The knowledge produced and transferred by a case study should be objective, rational, technical, structured and easy to share.

In summary, this section describes creation of awareness among decision makers as one of the key steps towards a strong leadership in construction organisations. Also, this section proposes the creation of explicit knowledge through the development of case studies of successful implementation of smart devices in the construction industry as a direct way of creating or increasing awareness. Creating awareness of the possible benefits of smart devices among the decision makers of an organisation, creates a change in leadership. Such change would give more awareness to the top management circle of the company of new means for innovation. The enrollment of the top management circle of an organisation leads towards the consideration and possible investment in new technologies.

8.2.2 Staff training and development

Training and development is initially defined by Swanson (1999) as “a process of developing work-related knowledge and skills in employees for the purpose of improving performance systematically”. Subsequently, Tabassi and Bakar (2009) cites Swanson (1999) on its definition. Strangely, the literature on training and development cites both sources, Tabassi and Bakar (2009) and Swanson (1999) on this definition. For example, Li *et al*. (2014) cites Swanson (1999) as the main sources, while Panas, Pantouvakis and Lambropoulos (2014); Gheni *et al*. (2016); and Wambui (2017) all refer to Tabassi and Bakar (2009).

A total of nice Interviewees (30% of responses) in the DR and UK mentioned staff training and development as a Critical success factor for implementing smart devices.

As explained by the following comment, in the DR, interviewees suggested that training should help employees, old and young, to compenetrate better with new technology in their workplace:

> *"…to provide training to most of the employees who don't have enough knowledge about this technology, because there are many older people and even younger ones who don't get along well with technology." (Interviewee DR-25).*

Similarly, in the UK, interviewees suggested that training should be a must to reduce resistant to change from part of the employees:

> *"What it also has to be is that when you implement these smart devices you will have people who are hesitant to use it, so training is a must" (Interviewee UK-10 - Part 1)*

The literature presents two dimensions on the topic of staff training and development in the construction sector. Firstly, smart devices can be used as a support tool to provide relevant information to construction staff. Particularly smartphones and tablets have a high level of portability and can provide contextual information (geolocation, weather, or geographic data) as required. They can be used to provide agile on-job-training to construction workers. More specifically, smart device such as smart boards can be used to support on-job-training to employees. Secondly, to obtain an efficient adoption of smart devices and the paradigm of the IoT, construction organisation are encouraged to provide training to their employees.

Smith (2002) presented two methods for training construction workers, namely, on-the-job and off-the-job training. On-the-job training is a pragmatic approach which promotes new practices. Following this approach workers typically received a course on new processes or regulations expected to be applied in their workplace (Tabassi and Bakar, 2009). Off-the-job training is a more curriculum-oriented approach which relies on classroom lectures, films or simulation exercises. This type of training can be used for developing technical and problem-solving skills. Off-the-job training emphasises on learning basic facts and skills whereas on-the-job training focuses on "getting the job done" (Tabassi and Bakar, 2009).

Despite the methodology used for staff training, this investigation needs to categorise the nature of training provided to the employees. Edum-Fotwe and McCaffer (2000) categorised the training options of construction project managers as follows: advanced technology in own field; Training in information technology; Management and human resources; Business studies; Marketing and sales; and languages. The issue with this categorisation is that back in the year 2000 the current paradigm of the industry 4.0 and the interconnection of objects through the IoT was not part of the context around construction organisations. Technology consultants stay up-to-date with the latest developments regarding the IoT and smart devices. Construction organisation should inquire with various technology consultants regarding the incidence of smart devices in management and human resources; business; marketing and sales; and languages. Ultimately, depending on the position of the employee, a training on smart device could be on any of the categories defined by Edum-Fotwe and McCaffer (2000), but with a more modern perspective.

Another important aspect regarding training and development of employees is their motivation to undertake training. Motivation is defined as "the characteristic of an individual willing to expend effort towards a particular set of behaviours" (Tabassi and Bakar, 2009). In the context of training and development of employees, motivation influences the willingness of staff to attend training, to exert energy toward the program, and to apply what is learnt in the program onto the workplace.

To motivate employees Tabassi and Bakar (2009) proposed to satisfy employees needs which can be broken down into worker participation, recognition and team belonging. To incentive workers participation, managers should use a training system which identifies and rewards financially workers who do a good job. Some authors prefer recognition rather than a financial reward. Nesan and Holt (1999) noted that giving an award of recognition to a team in an organisation can achieve significant success as opposed to rewards. Finally, team belonging, suggests that employees feel more motivated when they belong to a team where they feel as participating in a group. Nesan and Holt (1999) highlighted that teams are particularly more motivated when they get the chance to manage themselves.

Another dimension of the training and development was suggested by interviewee UK-09, who proposed that Universities should actively train new professionals on the latest technologies:

> *"…the place for that to be acquired is in University, the people who are going to be coming out to the industry really need to be taught before they get into the industry about these technologies and how to use these technologies"*
>
> *(Interviewee UK-09).*

Including an update on the latest technologies to students could certainly become a new way to insert new knowledge to the industry of construction through academia. It could affect the organisational culture of a company, and subsequently, a whole industry.

Ultimately, in order to motivate construction workers to adopt a new training system, this investigation recommends performing team building activities, provide award recognition to their employees and, in particular cases, financial reward could be considered. According to Tabassi and Bakar (2009) when employees feel that their participation is important in making the company successful, their work will manifest in a way that meet the organisation's needs and not only their owns. Similarly, Cheng and Ho (2001) highlighted that training motivation influences trainees' training performance.

8.2.3 Organisational culture

Organisational culture influences the way people set professional goals in the workplace, it affects the way in which people consciously and subconsciously think, ultimately defining the way how people perform tasks and administer resources to achieve them (Lok and Crawford, 2004).

UK interviewee UK-02 specifically suggested cultured as a challenge which becomes a success factor:

> *"It would be culture. As a challenge it links to success factors, people need cultural change and awareness. So, because you worked in the company for 30 years where people used to use drawings and paper and then things become digital, how can you adapt." (Interviewee UK-02)*

According to this comment, employees need a cultural change. This comment suggests that people working for many years in a company might find difficult to generate change towards digitalisation. Similarly, DR interviewee DR-24 explained that the mentality of the organisation should be considered as a critical success factor:

"I think that it has to be the mentality of the organisation. Then I think there is a lack of awareness of the benefits of implementing that technology." (Interviewee DR-24)

The mentality of the organisation which this investigation includes as part of the organisational culture is said by the interviewee to contribute with the lack of awareness regarding the benefits of implementing smart devices. What this finding reveal is that an appropriate organisational culture may bring innovation. Following this lead, the next step was to find in the literature what type of organisational culture we can call "appropriate" for bringing innovation to a construction company.

Previous investigations on organisational culture have identified distinct types of cultures. Goffe and Jones (1998) presented four types of organisational cultures, namely, networked, mercenary, fragmented and communal. Martin (1992) showed organisational culture from three perspectives: integration, differentiation and fragmentation. But even before that,

More recently, Liu *et al.* (2006) highlighted two basic approaches to study organisational culture, the typology approach and the dimensional approach. Liu *et al.* (2006) also highlighted the usefulness of Wallach (1983) typology approach on organisational culture. Wallach (1983) presented three types of organisational cultures which align with this investigation, namely, bureaucratic, supportive and innovative. Additionally, other investigations have found distinct perspective from which to analyse the dimensions of organisational culture, such as technological, socio-psychological, socio-structural (Liu *et al.*, 2006).

Following these findings from the literature, this study recommends construction organisations to address the all the dimensions of their innovative organisational culture. Consequently, construction firms should adopt an innovation culture.

An innovation culture is defined by Kenny and Reedy (2006) as “a way of thinking and behaving that creates, develops and establishes values and attitudes within a firm, which may in turn raise, accept and support ideas and changes involving an improvement in the functioning and efficiency of the firm, even though such changes may mean a conflict with conventional and traditional behaviour”. For construction firms to succeed at adopting this type of culture, Kenny and Reedy (2006) recommends four kinds of attitudes: (1) corporate management should be willing to take risks, (2) the participation of all members of the organisation should be requested, (3) creativity should be stimulated, (4) there should be shared responsibility. Additionally, Canalejo (1995) suggested the following values for firms to adopt an innovative organisational culture: client-orientation, commitment towards objective, challenge and initiative, exemplary behaviour, team work and permanent improvement.

In summary, this section presents the issue raised by the interviewees regarding their current organisational culture and how it is a critical factor to achieve a successful adoption of smart devices. The literature on innovation-based organisational culture is broad and well defined and allowed this study to make suggestions to construction firms. The attitudes and values to become adopt an innovative organisational culture are suggested to construction organisations.

8.2.4 Technology awareness

Technology awareness refers to the perception level from users towards the state of technology. Due to the ever-changing state of technology, being aware involves the constant gathering of information about changes in technology. One respondent stated that adopting a collective mentality about the benefits of smart devices in the industry will help to embrace this technology better.

> *"…what I see is that you have two types of professionals, I will not say young ones and old school, no. But you have people that investigate and know about current technologies, and others that have stayed in their traditional methods. Then that last group is the complicated one, first we need to show them what we can do, so we wide their perspective, and secondly, why they need it, that is understanding why they will change from their traditional way to a new one that at the beginning it might take a bit longer to adapt but on the longer path it will be better."* (Respondent DR-05)

This interviewee considers there are two groups of professionals within the construction industry. First a group of young profesionals who embrace and understand technology and its benefits, and then a group of older professionals who prefer more traditional methods and are resilient to innovate. To embrace the adoption of smart devices, it is necessary to create a common sense of awareness about the benefits of the implementation of technology. Another respondent focuses on young professionals in the industry, stating the following:

> *"…to provide more information to young professionals about the advantages and applications there are available, and that way is motivating us to prepare better."* (Respondent DR-11)

Establishing a collective mentality within the industry seems relevant to some construction organisations. According to the respondents, this is all about changing the perspective of the industry starting with younger generations:

> *"…adopting a collective mentality, that this technology is necessary, important and relevant." (Respondent DR-12)*

Also:

> *"...some people might not see the benefit (of Smart devices), but if the benefit are explained and graphed, then maybe people will change their perspective." (Respondent DR-15)*

These statements contemplate the education of professionals within the construction industry for a better understanding of the technological tools available. From these statements the following question arises: who is responsible for providing this education? the answer to that question could be narrowed down to the organisation and the government. It is a direct responsibility of the employer to offer capacitation to its employees. The government is in the capacity of creating policies for making this happen in the construction industry of the Dominican Republic. However, education institutions and professional bodies could provide courses such as continuous professional development, workshops, webinars, seminars to raise awareness and usage of smart device technology.

In summary, awareness of technological solutions is a critical factor for implementing technology in the construction industry, in this case, smart devices. The core principle of technology awareness is education; it is necessary to embed constant education to young and old professionals in the industry. Corporate culture tends to be a fundamental part of the awareness of the company. For example, bureaucratic structures impede and delay efforts for innovation (Burmeister *et al*., 2015). A more entrepreneurial mindset with higher degrees of freedom and responsibility for employees could mean a higher implementation of new technology. The organisation's culture can be directly linked to the awareness of its employees; this means that an increase in the awareness of technology within an organisation would required a change in the organisational culture.

8.2.5 Cost

The cost of the proposed solution is a critical factor to consider for a successful implementation of smart devices. The company size influences the ability of the organisation to implement new technologies. Large companies have larger budgets than small companies which makes it easier for them to implement new technology-based solutions. Larger companies sometimes have multi-city or multi-national projects which make them more likely to require the implementation of smart devices for project coordination. Ultimately, the cost of implementation plays a fundamental role in the decision-making process, as the following respondent noted:

> *"…when you have a company of certain level, the implementation of technology is necessary but is also expensive. It is easy to say 'let's implement it', but first you need to see the cost-benefit analysis. (Respondent DR-01)"*

The implementation of technology relies on the cost-benefit analysis of the proposed solution. For the decision makers, the implementation of smart devices means more expenses in the first instance. The provision of positive cost-benefit analysis would encourage the implementation of smart devices by showing the potential benefits to be achieved and how these benefits translate to earnings. If the cost-benefit analysis does not translate to either cost savings or time savings, then it will not be likely to be implemented. In a large company, the main motivation for implementing smart devices is to enhance the communication between the management workforce, because of the size of projects in large companies, communication enhancements usually translate in cost and time savings.

In summary, cost of implementation of smart devices must be analysed against potential cost savings gained from this implementation. The cost will depend on the type of devices to be implemented and the type of project being developed. In the construction project every project is different. Nevertheless projects can be grouped depending on their nature, for example, road project, building/housing project, bridge construction. Many other categories can be named based on the nature of the project, that is why is necessary consider the type of project to elaborate an accurate cost-benefit analysis on the implementation of smart devices.

8.2.6 Company size

Company size is an important demographic factor for sub-dividing research samples, different opinions and perceptions are usually found between different companies depending on their size. Lin and Mill (2001) indicates the contrast between large and small businesses in the construction sector regarding the need for implementation of an occupational health and safety system.

In the construction industry Small and Medicum Entreprises (SMEs) account for a majority of the construction companies. In the UK, in 2016, 99.5% of all 5.5 million businesses were small and medium sized (Rhodes, 2015). However, large companies accounted for 40% of all private sector employement. In the UK and DR, organisations are classified into micro, small, medium and large depending on their number of employees. This classification has been discussed in section 3.4.4.

Company size is directly linked to project size as small companies usually develop small projects. The size of the company and projects influences the way we analyse and understand the implementation of a new process in the construction industry. Al-Ghafly (1995) highlighted that the delay frequently occurred in medium and large size projects were considered severe in small projects. Consequently, it is necessary to consider and quantify this variable when developing a framework for implementation of any new technology. In the Dominican Republic, companies are divided into micro, small, medium and large. Each one of these group should have its path to innovation. Considering this classification respondents noted the following:

> *"I would say that depends a lot on the company size, because some companies are only one or two engineers with sub-contractors, on that case, the technology is limited for implementation, and they do not have the necessity or urgency to implement it. Now if they expand like this company which is bigger, then the agility of work helps to keep or improve the standard in which you are working. I think that's it, because it depends on the company size, if the company is small they will not have many resources." (Respondent DR-14)*

Also:

> *"The market size and the expected revenue influence. If my benefit margins are low, then I do not have to invest in things that will not necessarily give me any return. For example, some big companies here manage more than one project at the same time, and for that case, it is good to track where is your equipment, and what is everyone doing. If I am a manager with 10 of 15 projects, I cannot be in 15 projects at the same time, if I have people who are in the project with a smartphone that can send me what is happening and I can see everything that is going on, then it is convenient to have a smart phone … But if it's just me*

doing a building I would not get into the troubles of getting, for example, a Drone for the project. The market definitely influences." (Respondent DR-01)

According to professionals who work in the construction industry, small companies lack resources to invest in technology, whereas bigger companies have more projects which make it more necessary for the implementation of smart devices for improving communication between employees and allowing managers to handle more projects. This means that a micro company with one or two projects has very centralised information exchanged whereas a larger company have a more decentralised structure.

Larger companies tend to have more projects; this might require the implementation of smart devices to add mobility and enhance information exchange between the organisation stakeholders. On the contrary, smaller companies have fewer projects, in the case of a company with a single project the implementation of smart devices is tempered by the project size.

In summary, company size is considered a critical factor for the implementation of smart devices and other technology-based solutions. The variables behind company size are number of employees, number of projects and projects' size. Based on the respondents' opinions larger organisations have a clear advantage against smaller organisations mainly because of their budget, but at the same time, larger organisations have more circumstances which demand the utilisation of smart devices when compared to small organisations.

8.2.7 Usability

Usability describes the quality of user experience of a system and its interaction (Lv *et al.*, 2015) . Usability includes user's emotions. Emotion is a significant part of user's decision-making ability. Solutions based on smart devices should be user-friendly, this means that the interaction with users should encourage further implementation of such solutions. In agreement with these principles, respondents highlight usability as a key factor for a successful implementation of smart devices:

> *"the more user-friendly it is the better, that is the secret of a successful implementation." (Respondent DR-06)*

Also:

> *"… ease of use and fulfilling general requirements such as the network, having an existing infrastructure for them (Smart devices) to work." (Respondent DR-12)*

In addition, respondent 12 added other requirements such as network and existing infrastructure for supporting smart devices. There are several variables involved in the usability of smart devices in construction projects. Construction projects are very heterogeneous, having very particular conditions. The adoption of smart devices should consider the conditions of the projects and any change necessary prior the implementation of a technology-based solution.

Another important factor in usability is interoperability. The term interoperability refers to the ability of equipment to integrate and exchange information (Blanc-Serrier *et al.,* 2018). A lack of interoperability between information systems means organisations expend considerable time and resources when moving between, and within, projects. Hence, greater interoperability between systems is essential (Forbes, 2017).

When integrating a new technology which can be related to smart devices and the IoT, a key factor is the easiness of integration with current technologies. By embedding sensors and network connectivity, we can transform existing equipment into smart device or object. As the following comment explains, easiness of integration and interoperability eases the implementation of new technology:

> *"…for example the GPS implementation was easy because we just had to install a SIM card and one extra hardware, that was already there, we just had to do one extra thing, so the easiest it is and that is capturing information and it is giving me information anyways, then perfect let's do it. That is simple. But then if it is certain wearable that when I get there on the next day, I have to configure certain things. The more difficult an implementation is, then the easier it fails, and even more in this industry…" (Respondent DR-06)*

The interviewee suggests that difficulty in the integration of new technologies with existing equipment might hinder the implementation of technologies related to smart devices. There is a wide range of type of construction projects which require different equipment to operate. The idea behind the IoT is that any object in a construction project can be connected to a network of devices which gathers data about the project. To fulfil a migration from traditional construction to a new paradigm which considers the IoT, we must consider the interoperability between new and existing devices.

In summary, positive usability needs to provide ease of use from the user's perspective. The provision of a positive user experience requires awareness and preparation of the site conditions which might affect the usability of the devices, such as network infrastructure and location of the project. Organisations and consultants should consider the existing equipment when evaluating the utilisation of smart devices. The interoperability and integration of new devices with existing devices will result in a more scalable implementation. For a smart device to be interoperable with other devices in needs to be able to communicate through a network and exchange information. On the other hand, integration requires a deeper union between two or more devices which end up acting like one. In the scheme of the IoT, two integrated devices will represent one entity in the network.

8.3 Summary

This chapter describes the CSFs for implementing smart devices in construction projects. The CSFs were obtained from a qualitative data collection and analysis. In total there were 39 semi-structured interviews from professionals in the field of Construction of the Dominican Republic and the United Kingdom.

The CSFs presented in this chapter were Leadership, Technology awareness, company size, usability, cost of implementation and interoperability. 36% of interviewees recommended leadership as a CSF, being this one the most relevant CSF commented by the interviewees. It was found that one of the main steps towards increasing leadership in a construction project is adopting a collective mentality about which technology is helpful for construction projects. Also, a critical step towards the implementation of any new paradigm is convincing the decision makers of a company about the benefits of such implementation. The enrolment of the decision makers into a new technology was said to be a good strategy towards increasing leadership and adopting smart devices.

Technology awareness addressed the perception level from users towards the state of technology. This CSF highlighted the importance of education of professionals within the construction industry for a better understanding of the technological tools available in the market.

Company size was an important characteristic to consider. According to professionals who work in the construction industry, small companies lack resources to invest in technology, whereas bigger companies have more projects which make it more necessary for the implementation of smart devices for improving communication between employees and allowing managers to handle more projects. Usability, cost of implementation and interoperability were the CSF least mentioned by the interviewees.

This chapter has addressed the fifth research objective of this study which is to investigate the Critical factors for successfully implementing smart devices in the construction sector. Also, the sixth research questions of this study has been addressed. The following chapter discusses the Strategic framework for implementing smart devices in the construction industry.

Chapter 9: Strategic framework for implementing smart devices in the construction sector

9.1 Introduction

This chapter presents a strategic framework for implementing smart devices in construction organisations. The findings from previous stages of this investigation were considered in the development of the framework. The developed framework provides a better understanding of the driving and restraining forces for implementing smart devices in the construction industry. It also provides an interpretative approach to a social reality of the construction sector. This framework aims at driving economic growth and labour efficiency by embedding the paradigm of the Internet of Things (IoT) in the construction sector. In doing so, this chapter addresses the seventh research objective of this investigation, which is “to develop a strategic framework for successfully implement smart devices in the construction industry”

This chapter is structured as follows: Section 9.2 explains the rationale behind the proposed framework; Section 9.3 and 9.4 explain the vision and aim of the developed framework; Section 9.5 defines the target audience of this framework; Section 9.6 explains the structure and functionalities of the developed framework; The validation of the proposed framework is presented in section 9.7. Finally, section 9.8 presents a summary of this chapter.

9.2 Rationale for a strategic framework in the construction sector

The construction industry was considered to have fragmented, multi-participant, project-based supply chain (Andresen *et al.,* 2002). A more recent study performed by (Box, 2014) shows that the construction industry has a higher need for the integration of smart devices in comparison to other sectors, namely: software; media and entertainment; manufacturing and financial services. In addition, Crotty (2013, p. 25-28) establishes the key challenges of the construction industry as lack of predictability and low profitability. In summary, the challenges of the construction industry are its fragmentation, multiparticipant project-based nature, lack of predictability and low profitability.

According to Crotty (2013, p. 25-28) The key solution to these problems consists of improving communication. Smart devices and the IoT have proven to be very efficient tools to improve information exchange and quality of communication between stakeholders (See chapter 5). The IoT is a network that connects things. Anything can be connected to this network. The IoT interconnects uniquely identifiable embedded computing devices. That means any device can be connected (Miller, 2015). Ultimately, this network enables any work environment with automated machines and metrics which improve communication, efficiency and prevents errors.

The contribution of smart devices in communication and quality of information exchange justifies the need for a framework of implementation. However, the opinion of the interviewees and the context of the UK construction industry was also considered to justify the need for a strategic framework.

This investigation researches the construction industry of the United Kingdom (UK) and the Dominican Republic (See Chapter 3 – Research Methodology). From the perspective of the UK, Embedding IoT and smart devices into construction is an important initiative for the UK government. UK government's Digital Built Britain strategy (HM Government, 2015) made clear their intention of improving the industry's performance through achieving the goals of 33% reduction in initial cost of construction and the whole cost of built assets. According to HM Government (2015) these and other improvements are meant to be achieved by enabling data collaboration between design, construction and operation of assets in the supply chain; also, through the integration of infrastructure with control systems. The UK government's strategy addresses the key ideas behind smart construction as a new way to design, delivery and operate construction processes, built on top of the paradigm of the IoT.

Interviewees who participated in the qualitative data collection of this investigation have shown their interest to obtain and utilise a framework or set of guidelines for integrate smart devices in their construction processes. The Interviewees were asked for the need of a set of guidelines or framework for implementing smart devices in the construction industry. 90% (35 of the 39) of the interviewees expressed the need for a framework or set of guidelines for implementing smart devices in the construction industry.

The above-mentioned situations in the UK and DR context, together with the issues raised from the analysis of the data collected from 39 interviewees gave validity for the need to develop a framework for implementing Smart devices in the construction sector.

9.3 Vision

Driving economic growth and labour efficiency by embedding the smart devices in the construction industry.

9.4 Aim

- **Incentive** construction organisation to **adopt smart devices**.
    - For construction companies which are not certain about implementing smart devices in their projects, this framework will provide the certainty required to implement smart devices.
- Provide **a strategic plan** for **implementing smart devices**.
    - For construction companies which have decided to implement smart devices.

9.5 Who is this framework for?

This is a strategic framework for organisations who wish to implement the IoT in the construction industry. This framework intends to provide a better understanding about the driving and restraining forces to organisations in the construction sector.

The proposed framework follows the innovation-decision paradigm explained by Rogers and Shoemaker (1983) to proposes a persuasion – decision structure to incentive a successful implementation of smart devices in construction projects. It also provides an Implementation - confirmation structure to be used for the embedment and adoption of smart devices into construction projects, from the design stage, until construction stage. It does not encompass the installation and utilisation of smart devices in the Built environment. Better said, it is for construction organisations which are developing construction projects and will benefit from the implementation of technologic advancements.

The developed framework is designed for organisations who have been exposed to the existence and gains of smart devices and the paradigm IoT. Such organisations should have some understanding of how the related technologies of this paradigm work.

9.6 Proposed framework for implementing smart devices in the construction sector

This framework proposes a strategic plan for construction organisations to embed and adopt smart devices into their daily activities in the construction industry. The proposed framework consists of two sub-frameworks, namely persuasion framework and implementation. Both frameworks follow the innovation-decision paradigm explained by Rogers and Shoemaker (1983) which conceptualises the innovation-decision process in five stages, as shown below (See Figure 9.1):

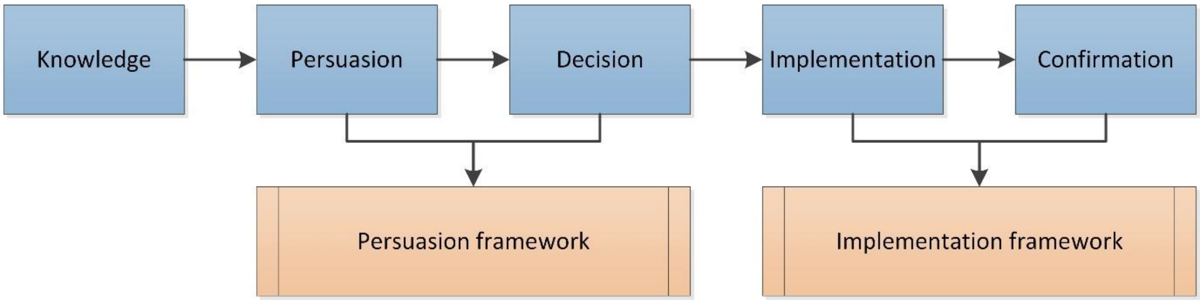

Figure 9.1:Rogers' Innovation-decision process and its relationship with the developed framework

Adapted from Rogers and Shoemaker (1983)

Rogers and Shoemaker (1983) established that the innovation-decision process starts with when an individual gains awareness of an innovation's existence and its benefits, which in this case would be smart devices. Then the persuasion stage comes when the individual generates a favourable or unfavourable perception towards the innovation. At this point the proposed framework presents a list of critical actions to incentive technological innovation. These actions can persuade the decision makers and employees of construction organisations about the positive benefits that come from the adoption of smart devices.

The decision stage occurs when and individual or organisation engages in activities that lead to a choice to implement or reject the innovation. As seen on Figure 9.1 the presented list of actions to incentive the implementation of smart devices, provides assistance with the enrolling of individual or organisations into a positive perspective towards smart devices.

The implementation stage takes place when the organisation puts an innovation into use. Furthermore, the confirmation stage of rogers' innovation-decision model occurs when the organisation seeks reinforcement of an innovation already adopted. The presented framework can provide assistance at this stage as well, therefore, companies which have already implemented smart devices can use the proposed framework to revise and improve their IoT systems.

The proposed framework firstly proposes a persuasion framework, showing a list of critical actions to incentive technological innovation in the Construction industry is presented, focusing on recommended actions to implement in the organisational context and external environment context.

Secondly, an implementation framework is presented, showing an iterative process between a construction company and an IoT system provider. The actors and elements of this framework are defined and justified. The implementation framework aims to guide construction organisation throughout the adoption of Smart devices. This framework targets the implementation and confirmation stage of Roger's innovation-decision stage.

The persuasion framework is designed for companies which have not yet decided to formally adopt smart devices in their processes. This framework should attract more technological innovation into construction companies. Subsequently, construction companies will use the implementation framework as a strategic guide to implement smart devices. Both frameworks can be used separately.

9.6.1 Persuasion framework

This framework presents a list of recommended actions to incentive a technological innovation in the Construction industry which translate into the implementation of smart devices (see Figure 9.2). The data collected in this investigation has shown a list of actions/recommendations which can contribute to the innovation of the industry.

The recommendations shown in this framework are built on top of the Technology-organisation-environment framework which is described in Tornatzky, Fleischer and

Chakrabarti's process of Technological Innovation (Tornatzky *et al.*, 1990). A more recent analysis on this framework made by Baker (2012) was also considered in the building process of this framework.

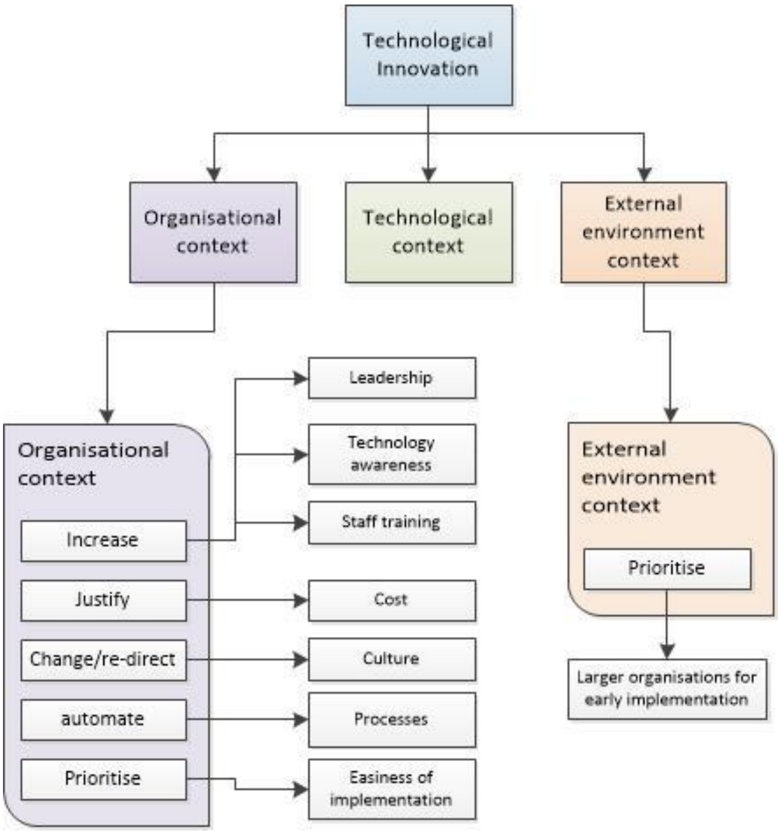

Figure 9.2: Persuasion-Decision framework - Critical actions to incentive technological innovation in the construction sector

To understand this framework, first construction organisations need to be aware of the process by which a firm adopts and implements technological innovations. Such process is influenced by the organisational context, technological context and external environment context (Tornatzky *et al.*, 1990) and (Baker ,2012). This framework can contribute to both the organisational context and external environment context within the technological innovation framework of construction organisations.

The organisational context encompasses the features and resources of the firm, such as linking structures between employees, communication processes, company size and availability of resources (Baker, 2012). The technological context addresses all the relevant technologies to the organisation, both technologies being used and available technologies in the marketplace to implement (Baker, 2012). The external environment context describes the structure of the industry, the availability of technology service providers, and the regulatory environment (Baker, 2012).

Hence the data collection performed in this investigation was made on an organisational level (See Chapter 4 – Research Methodology) the findings are mostly on the organisational context. Data analysis also revealed some recommendations for the external environment context. The technological context has no recommendations from the data analysis, nevertheless, a description of this context based on the existing literature is provided.

Chapter 8 presents the findings regarding the Critical Success Factors for implementing smart devices in the construction sector. Subsequent data analysis and corroboration with the literature allowed the research team to frame those findings within the Technology-organisation-environment framework described in Tornatzky, Fleischer and chakrabarti's process of Technological Innovation (Tornatzky *et al.*, 1990).

9.6.1.1 Organisational context

As can be seen in Figure 9.2 within the organisational context there are various actions for construction firms to undertake. They are encouraged to increase leadership, technology awareness and staff training; justify the cost of IoT systems in construction project; Create a change or re-direction in the culture of staff towards the implementation of technology; automate construction processes; and prioritise IoT systems which are easier to implement and integrate with existing technology;

Increasing leadership relies on enrolling the decision makers into embedding smart devices in the operational processes of the organisation. Creating awareness among decision makers about the potential benefits of smart devices is the critical path towards adopting a new technology solution in a construction company. A case study of successful implementation of smart devices in a construction project will promote positively any new technology among the decision makers.

Increasing the awareness of the state of the IoT enhances the perception level of the workforce and decision makers towards this technology. Being aware of technology involves a constant collection of information about the updates in IoT technology. Furthermore, increasing the staff training contributes to a higher awareness of technology and a more efficient implementation of smart devices.

Another important component is the cost of implementation. Smaller companies are less likely to implement new technologies without a positive cost-benefit analysis or Return of Investment (ROI). Technologies like Daqri Helmet which by 2018 cost $15,000 (US dollars) represent a high cost for small and medium companies. Health and safety is an entrance door for robots, which can be used in hazardous environment to substitute human labour. Although it might be expensive to send a robot to inspect a hazardous site, it might be necessary due to existing dangers onsite. One example is the scouring inspections of bridges, which requires divers to be sent to the water. Time savings are also an important dimension of a construction project to consider. Time savings can be a crucial factor when planning a project, since some project are needed to be finished within a strict timeframe.

The cultural aspect of an organisation relies on many socio-economic factors, as well as geographic ones. Within both developed and developing countries we can find companies which are either to adopt a new paradigm and companies who are reluctant to new implementations. As previously mentioned a case study of a successful implementation can promote a healthy implementation within a sceptical organisation. Nevertheless, to embed new technology into the processes of an organisation means to remodel such processes. The culture of individuals towards adopting new technology can be unexpected and should be evaluated and re-educated. The term re-education in this research refers changing the perspective of staff to be more receptive towards new technology.

Finally, a critical step towards the incentive of the adoption of the IoT and smart devices in construction projects is the automation of processes prior an initial implementation of a new system. This idea is better understood with an example of implementation: Let’s pretend that in certain company which is already using smartphones and tablets in their projects wishes to adopt a smart board because it adapts to an existing large number of meetings taking place among various stakeholders. If we consider the current way of doing things in the organisation, then the purchase of a smart board might seem logic. Nevertheless, by optimising the processes of the company and maybe changing the project management system and applying a better use their existing smartphones and tablets they might reduce the need for meetings and the need for a smartboard might be even eliminated. The point is that smart devices are constantly and swiftly evolving, and the inclusion of new devices should consider the automation of the existing ones.

9.6.1.2 External environment context

The data analysis presented in Chapter 9 regarding the Critical Success Factors for implementing smart devices in the construction sector indicates that the external environment context should prioritise medium and large companies over smaller ones, due to their scope of operation and easiness to become pioneers rather than fast followers of new technology. Rogers and Shoemaker (1983) corroborate this with a set of generalisations about early and late knowers of innovations. According to Rogers and Shoemaker (1983):

- Generalisation 1: Earlier knowers of an innovation have more education than later knowers.
- Generalisation 2: Earlier knowers of an innovation have higher social status than later knowers.
- Generalisation 3: Earlier knowers of an innovation have more exposure to mass media channels of communication than later knowers.
- Generalisation 4: Earlier knowers of an innovation have more exposure to interpersonal channels of communication than later knowers.
- Generalisation 5: Earlier knowers of an innovation have more change agent contact than later knowers.
- Generalisation 6: Earlier knowers of an innovation have more social participation than later knowers.
- Generalisation 7: Earlier knowers of an innovation are more cosmopolite than later knowers.

Large and medium companies have a clear advantage against micro and small companies when compared using the generalisations of Rogers and Shoemaker

(1983). However, regardless of the company size an important variable to consider within the external environment context is the “chasm” defined by Geoffrey Moore (Moore, 1991). According to Moore, a technology adoption life cycle starts with innovators (2.5%), followed by early adopters (13.5%), early majority (34%), late majority (34%) and laggards (16%). As can be seen in Figure 9.3 the chasm is crossed once most of the customers agree on the convenience of the product.

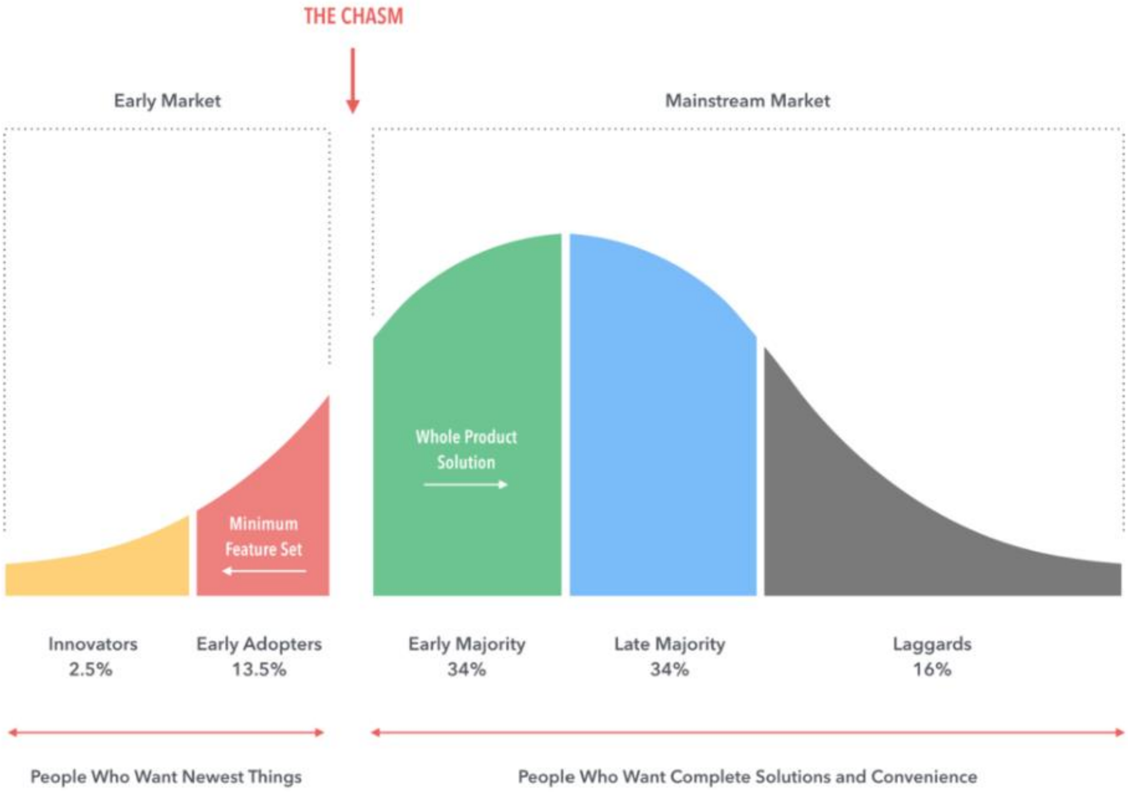

Figure 9.3: Diagram of the "chasm". Adapted from Moore (1991).

This theory initially focuses on advising companies which offer a novel technological product. Construction organisations which embed smart devices into their daily operations should see themselves as innovators offering a new product. These companies will have to (using Moore’s words) cross the “chasm”.

9.6.1.3 Technological context

The technological context includes all the technologies that are relevant to the construction organisation (Baker, 2012). It is both the technologies that are already being implemented within the organisation and the ones available in the marketplace for adoption.

Within the innovations that exist outside the construction organisation, there are three groups or types, namely, incremental, synthetic, and discontinuous innovations (Tushman and Nadler, 1986). Baker (2012) explains these distinct technological innovations as follow:

- The innovations that produce in incremental change bring either new features or new versions of existing technologies.
- Innovations which produce synthetic change present a mixture of ideas and technologies combined in a novel manner (i.e.: Universities' delivery of Open Online Courses).
- Innovations which produce a discontinuous change present a radical transition from current technology. An example shifts to cloud computing that began in the early 2000s.

9.6.2 Implementation framework

This framework consists of a strategic action plan to implement IoT systems in a construction organisation. This section presents the concepts and structure of the proposed framework. The actors of the framework are: Construction company, IoT system provider, and IoT system. The specifications of the company are an important element which is further explained in section 9.6.2.2. A feasibility analysis which consider important elements obtained from the data collection of this investigation and the literature is explained in section 9.6.2.3. The workflow of the framework is discussed in section 9.6.2.4. Overall, the framework establishes an iterative process in which the IoT system provider and the construction company exchange information, to define the most optimum IoT system to implement (See Figure 9.4).

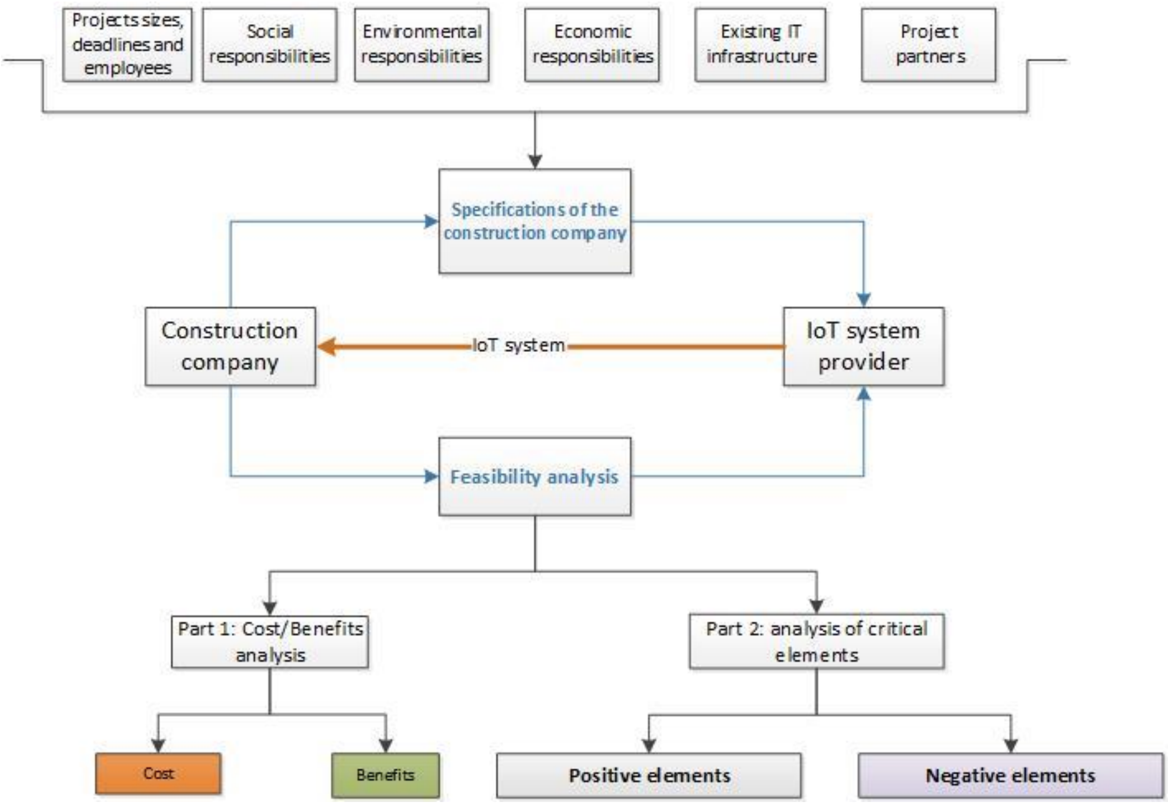

Figure 9.4: Workflow of Implementation framework

Due to the project-based nature of the construction sector (Andresen *et al.,* 2002; This framework is initially designed to be used on a project level. Nevertheless, a multi-project implementation is possible if not desirable. And IoT system will attempt to increase communication and mobility in between projects which can help to reduce the fragmentation of the construction industry's stakeholders (Box, 2014).

The development of this framework considered the findings presented in Chapters 6, 7 and 8, regarding the main utilisations, drivers and challengers, and critical success factors for implementing smart devices in the construction sector. Additionally, data obtained from a critical review of the literature assisted in the elaboration process of this framework.

The implementation of this framework generates beneficial output a construction organisation firm and its stakeholders. This framework should be looked at as a system which generates valuable information for adopting smart devices into a company’s processes. As an evidence of this Figure 9.5 shows the outcomes obtained after successfully implementation of each stage of the framework. The outcomes of this framework do not lose relevance after a new stage is accomplished, therefore, an organisation must keep track of these results and re-visit as their development demands it. The simplest example is the output of stage 1, which can be useful to accomplish a different goal than only this framework.

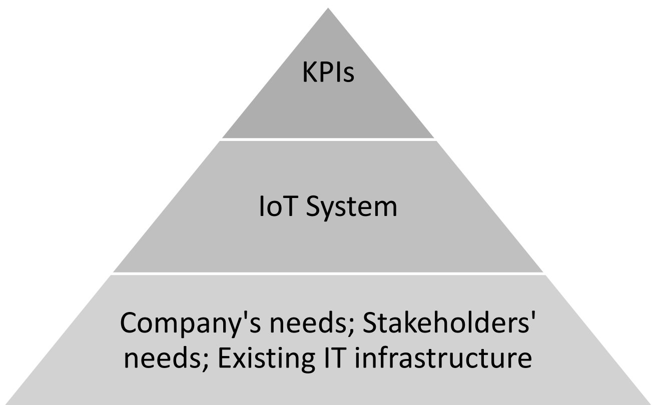

Figure 9.5: Pyramid of output produced by the proposed framework

9.6.2.1 Actors

- **Construction company:** a company which delivers services to any type of client in the construction industry.
  - For example: Construction firm, Façade company, Structural design company, Architecture study, Management and supervision company, Painting company, Plumbing company.
- **IoT service provider:** a company dedicated to providing consultancy for Information Technology IT.
  - In this case this company will provide advice about the best IoT system to implement.
- **IoT system:** Internet of Things system. It is a group of distinct computing technologies working together.
  - It can include: smartphones, tablets, servers, laptops, Wi-Fi networks, cameras or smartboards.
  - A typical IT (Information Technology) system focuses on computing machines.
  - An IoT system encompasses an IT system plus smart devices that might be beneficial for the company.

9.6.2.2 Specifications of the construction company

The specifications of the construction company are a requirement for obtaining an IoT system. As can be seen in Figure 9.6 these specifications include information such as project specifications, social, economic and environmental responsibilities, existing IT infrastructure and project partners.

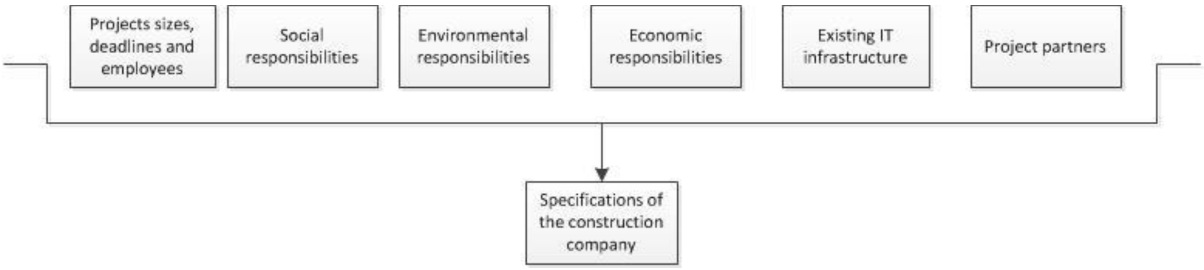

Figure 9.6: Specifications of the construction company

The projects specifications should include elements such as deadlines, aim of the project, project size, communication requirement, and any other information that might be relevant to the technology consultants. It should also describe the social, economic and environmental responsibility of the project.

The existing equipment of the company and their capacity to integrate with new technology and smart devices also comprise relevant data to include into the input of the framework. A performance analysis of existing technology being utilised by the organisation, will provide important metric in order to enhance the productivity of the company and improve the efficiency of smart devices in the workplace.

The term project partners refer to all stakeholders of the project. A broad definition of stakeholder is brought by Freeman (2010) who describes stakeholder as:

> *"any group or individual who can affect or is affected by the achievement of the organization's objectives"*

Nevertheless, Eden and Ackermann (1998) empowered the concept of stakeholder with their definition:

"People or small groups with the power to respond to, negotiate with, and change the strategic future of the organization"

A handful definition is provided by the stakeholder map website, which defines stakeholder as:

"Anybody who can affect or is affected by an organisation, strategy or project. They can be internal or external and they can be at senior or junior levels". (Stakeholdermap.com, 2018)

Once we have identified our stakeholders and mapped their positive or negative impact in the project, we need to draw a deep understanding of their needs and how the organisation links with such needs. Also, we should list the technological resources of the stakeholders under consideration for input in the framework.

9.6.2.3 Feasibility analysis

The feasibility analysis presents two processes for defining the most convenient implementation for the construction firm. Figure 9.7 illustrates the structure this stage and its processes. Firstly, a cost/benefit analysis is required where both direct and indirect costs are considered, also the distinct types of benefits should be addressed. Secondly, an analysis of various critical elements must be performed; these elements might be of high relevance and helpfulness for decision makers. For example: health and safety conditions might require the utilisation of robots, drones or other unmanned devices to make certain construction processes safer. Also, the project location might indicate that it is not safe to provide expensive devices to the employees.

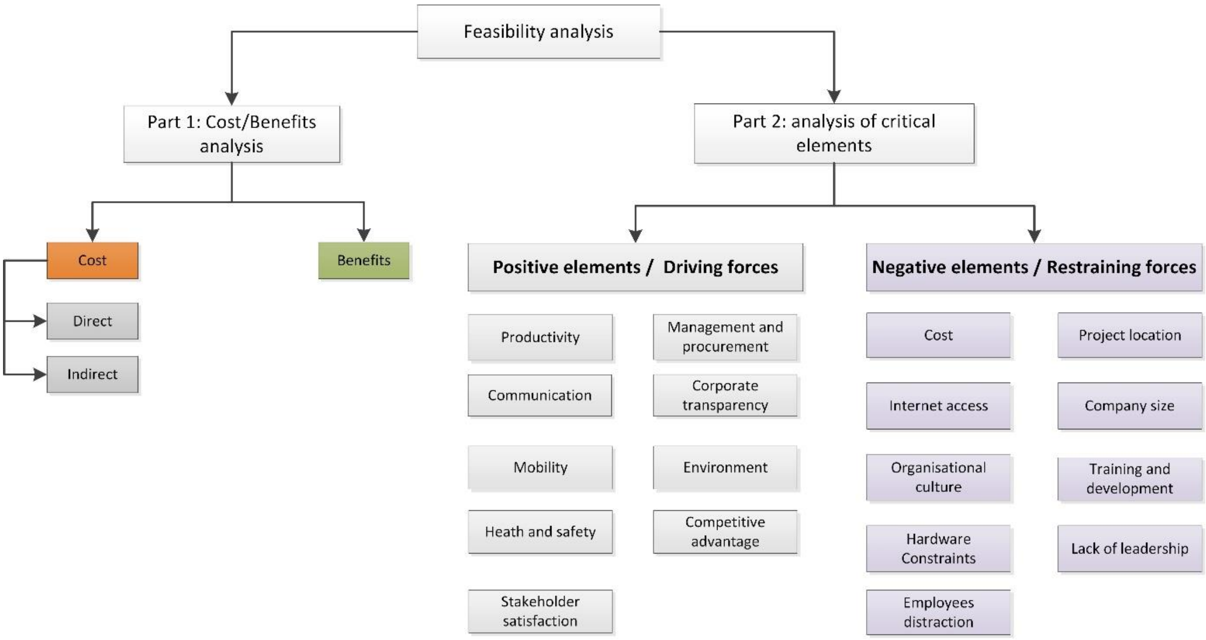

Figure 9.7: Feasibility analysis diagram

9.6.2.3.1 Cost/benefit analysis

The evaluation of Information Technology (IT) is a process that searches for quantitative and qualitative impacts of the proposed system into the projects (Land *et al.,* 1999). An IoT system is found within the sub-domain of IT therefore the literature regarding the evaluation and appraisal of IT system can be used to orient this section of the framework. Justifying the investments in an IoT project is one of the most challenging steps in the implementation process of IoT systems. Similarly, Love and Irani (2001) shows that the justification of investments in IT is one of the many challenges facing managers in the construction industry.

Cost/benefit analysis plays a fundamental role in the evaluation process of a IoT project within the construction industry. Regrettably, the construction industry, has a background of neglecting the indirect costs and benefits of the implementation of IT (Love and Irani, 2001). This happens when the justification processes used by construction organisations are based on traditional appraisal techniques. Nevertheless, the process of quantifying the cost of IT implementation is difficult and complex and time-consuming (Love *et al.*, 2000), therefore, it is a challenge in the appraisal of IoT systems.

Another important variable to consider is Return of Investment (ROI). The implementation of a technological innovation in one stakeholder could represent a higher ROI for a different stakeholder, just as it happens with BIM (Walasek and Barszcz, 2017). ROI of smart devices is difficult to quantify due to the tangible and intangible factors around it. However, it should be considered as an important variable of a feasibility analysis.

This stage of the framework's process section focuses on presenting the tools and recommendation for apprising IoT systems quantitatively. The idea behind a correct appraisal of an IoT consists of considering all the possible variables surrounding the implementation of an IoT system. Consequently, a construction firm can choose to adopt a level of implementation which will benefit them.

Cost and benefits always play a crucial role in all the decision makings. A cost benefit analysis would provide an additional dimension of analysis to the decision makers of the company when it comes the time to decide the level of adoption of smart devices. This variable will establish a clear boundary of to what the maximum implementation is feasible for the company.

To appraise the cost and benefits from the implementation of IoT systems, this framework recommends following the taxonomy of investment appraisal techniques established by Love and Irani (2001). This taxonomy proposes a strategic appraisal technique which considers variables such as technical importance, competitive advantage, Research and Development and Critical Success Factors.

In addition, construction firms must consider both direct and indirect costs embedded in the IoT systems proposed by the technology consultants. Such cost can be categorised as indirect human cost and indirect organisational cost. Figure 9.8 illustrates the direct and indirect costs associated with construction projects based on Love and Irani (2001); Irani *et al*. (2001); and Love and Irani (2004)

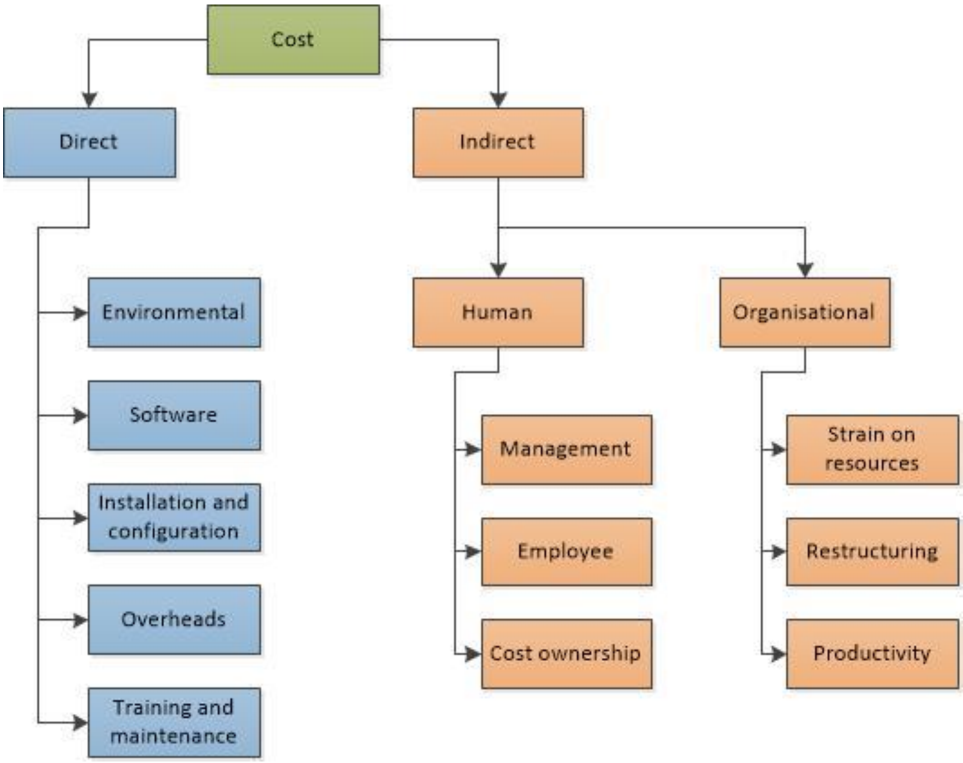

Figure 9.8: Scheme of types of cost in construction projects

Adapted from Love and Irani (2001); Irani et al. (2001); and Love and Irani (2004)

The indirect costs embedded in a construction project tend to be difficult to quantify Love and Irani (2001). The indirect human cost related to construction projects can be associated to management, employees and cost ownership. Management cost may derive from management resources, management time, management effort and dedication. Employees cost may come from employee time, employee motivation, employee training and personnel issues. Cost of ownership includes features such as system support and troubleshooting costs. According to Love *et al*., (2000) Management time is considered as the most significant indirect cost to construction organisations. The implementation of new technology translates into management time spent planning the integration of new systems into the workplace. This could force the management to spend additional time in revising their IT-related strategies.

The indirect organisational cost related to construction projects can be associated to Strain of resources, restructuring of the organisation, and losses of productivity. The restructuring that takes place within the organisation may include organisational restructuring and business process re-engineering.

The quantification of benefits presents a similar challenge as with the quantification of costs, the benefits behind an IoT investment is hard to identify and quantify and the intangible factors present can be significant. Powell (1992) and Andresen *et al.,* (2002) corroborate this, explaining that evaluating or justifying investment in IT is troublesome.

Construction firms must also consider the distinct benefits associated to construction projects. Andresen *et al.,* (2002) defined a framework for measuring the benefits associated with IT innovation. Within this framework the benefits from implementing IT in construction projects are grouped into efficiency, effectiveness and performance benefits. Andresen *et al.,* (2002) state that efficiency benefits are quantifiable and can be represented by money. Performance benefits are qualitative and are measured based on the impact of a successful implementation in influencing long-term business performance. Finally, effectiveness benefits are measured in improved operations.

Table 9.1 suggests a list of benefits which a construction organisation can use to in their feasibility analysis. Although more benefits can be found in a construction project. The list of benefits suggested in Table 9.1 aims at clarifying the differences between efficiency, performance and effectiveness benefits.

Table 9.1: 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 more enquiries	Improved idea sharing among projects teams	More responsive ability to arrange meetings
Reduced communication costs	Improved project relationships with strategic partners	Improved quality of output
Reduced paperwork	Improved full life-cycle information management	Enhanced ability to exchange data
Reduced procurement costs	more effective assembly of project teams	Improved control of cash flow
Reduced procurement times	Improved human relations	
Reduced construction times	Increased responsiveness of senior management to business problems	
Improved productivity		
Reduced operational costs		

The main issue behind the quantification of costs and benefits of a new IoT systems is the lack of data regarding the efficiency benefits, performance benefits and the indirect costs incurred. The outcome of this stage is a feasibility analysis, which considers direct and indirect costs, as well as efficiency, performance and effectiveness benefits.

9.6.2.3.2 Critical elements analysis

Chapter 6 and 7 discuss the drivers and challenges around the implementation of smart devices. It was found that certain elements play a crucial role for decision makers, thus become more relevant than the cost of the IoT system itself. Such elements are presented in Figure 9.9. As can be seen, there are positive elements or driving forces and negative element or restraining forces against the implementation of smart devices. For example, health and safety might be more important for a construction organisation due to its nature of operation and might stand above a high cost of implementation.

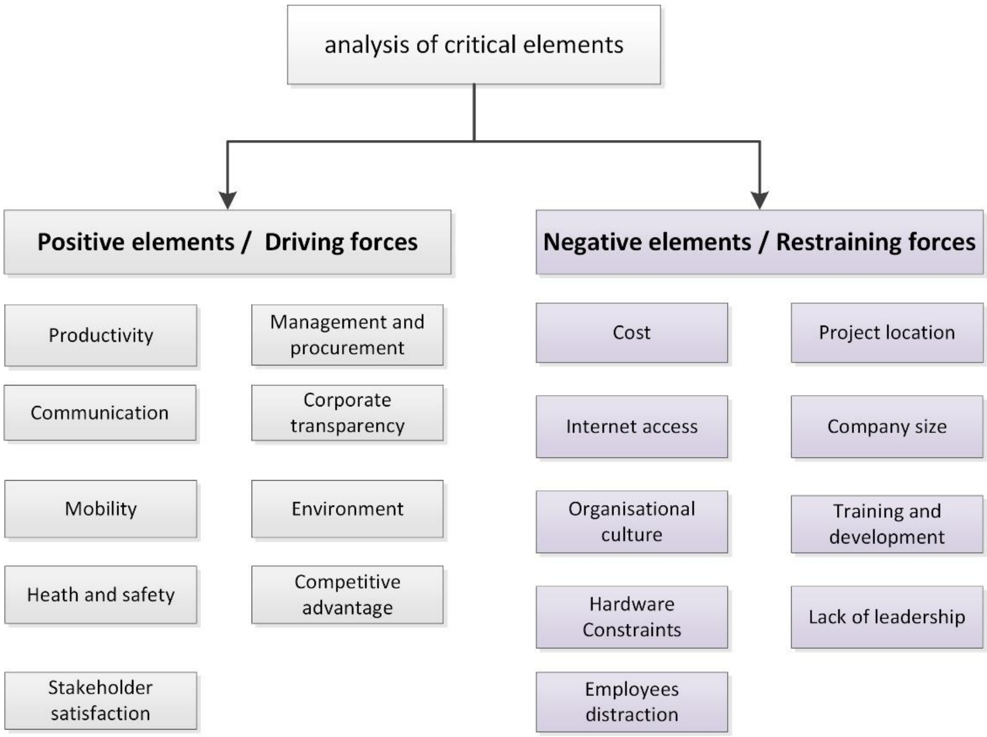

Figure 9.9: Driving vs Restraining forces for implementing smart devices in the construction sector

There are situations where we find critical elements that directs the organisation towards implementing smart devices. For example, a construction firm might be asked to finish a project within a specific timeframe, and smart devices might be one of the main factors for succeeding at this. There might be some budget requirements which can only be achieve with a cost reduction obtained with the use of mobile cloud computing. A project might require managers to be geographically separated and might need to perform video calls every week. Or the company might have a strong health and safety culture which might push forward the implementation of unmanned devices for health and safety reasons (just as presented in Chapter 6 and 7).

There are many situation where smart devices might be required regardless of the results of a feasibility analysis. Some elements are indispensable the realisation of the project. These elements are catalogue as driving forces for the implementation of smart devices in construction projects.

Furthermore, there restraining forces which prevent the implementation of IoT systems in construction projects. These forces might play an adverse role in the implementation of smart devices and need to be considered. For example, a cost/benefit analysis could indicate that positive revenue, but the culture of the company might be a challenge to overcome for things to work as planned. In addition, there could be a lack of leadership from the management force to adopt change.

This framework recommends considering both driving and restraining forces at the time of implementing an IoT system. Construction firms should analyse the list of driving and restraining forces and select what are the critical elements that adapt to their staff and socio-economic situation.

9.6.2.4 Framework workflow

This section explains the workflow of the implementation framework, utilising the actors, company specifications and feasibility analysis described above. Figure 9.4 shows the workflow for implementing the mot adequate IoT system in a construction company.

As can be seen in Figure 9.4, the **construction company** needs to provide its **specifications** and **feasibility analysis** to the **IoT service provider**. The IoT service provider will provide an IoT system for the construction company to implement.

This is an *iterative process*, in which the IoT service provider can participate in the feasibility analysis of the construction company. The IoT service provider and the construction company will negotiate the best proposal. A new IoT system might be proposed by the IoT service provider which will be analysed by the construction company. Then the construction company would show their feasibility analysis to the IoT service provider. This process finishes when the construction company selects an IoT system.

9.6.2.5 Definition of KPIs

The result of previous stages will generate a list of recommended IoT systems or Smart devices for the construction organisation. This will consider the quantitative and qualitative feasibility, as well as the critical elements presented in the previous stage.

This section aims at providing support and guidance to establish a Performance Measurement System (PMS) to measure and monitor Key Performance Indicators (KPIs) throughout the construction projects of the construction firm which uses this framework.

Parting from the premise that a construction organisation must establish a mechanism for performance measurement. The literature on performance measurement is very well established within the academic community. According to Neely *et al.*, (1995) Performance measurement is defined as

"The process of quantifying effectiveness and efficiency of actions."

Moreover, Neely *et al.*, (1995) defines Performance Measurement System (PMS) as

> *"The set of metrics used to quantify both the efficiency and effectiveness of actions."*

Around the world distinct benchmarking initiatives have been adopted within the construction industry in order to establish a PMS which measures the performance of the industry. The United Kingdom launched the Key Performance Indicators (KPI) program in 1998 (Costa *et al.*, 2006). This program is supported by the government through national and regional offices.

Costa *et al.,* (2006) addresses the implementation process of KPIs: To implement KPIs, companies receive a support handbook, guidance for measurement, and access to online software. The construction organisations are responsible for collecting data, introducing them into the database, and updating them. The companies can access reports and benchmark score and allow an organisation's score to be benchmarked against a large sample across the industry.

The performance measurement to be implemented will rely on the country of implementation. And the philosophy within the organisation. Lebas (1995) considers a PMS as the organisation shared vision, teamwork, training, incentives, etc. that surround the performance measurement activity.

The variables to be included within the Performance measurement process should consider the feasibility analysis and critical elements discussed in the processing stage of this framework. The construction organisation should consider the distinct types of variables to be measured. Table 9.2 presents a good guidance of objective and subjective measures to record KPIs offered by Chan and Chan (2004).

Construction organisations should consider the following challenges to the implementation of performance measurement systems in the construction industry (Costa and Formoso, 2004):

- Construction is a project-oriented industry and each project is unique.
- The establishment of KPIs and a PMS requires intense effort
- The responsibilities for data collection, processing and analysis of KPIs are usually not well defined.
- Each project usually has a different management teams with distinct leadership attitude.

Table 9.2: KPIs Objective and subjective measures

Adapted from Chan and Chan (2004)

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

9.7 Validation of the framework

Chapter 3 explains the methodology followed to validate the proposed framework. In summary, the validation process consisted of creating a guide which explains the framework. This guide consist of a PDF file which was sent to the most experienced participants of the study.

The developed framework was validated by Five senior professionals of the Construction industry. Two participants were selected from the United Kingdom and Three more from the Dominican Republic. The framework's guide was sent to the professionals through email, together a link to an online questionnaire to review the developed framework. The participants selected were required to provide constructive feedback on the developed framework. The validation process was held between January 2019 and February 2019. The feedback received by the participants of the validation process was incorporated into the framework presented on this chapter.

The feedback given by the participants of the validation process consisted of five aspects:

9.7.1 Feedback received from interviewees during validation process

9.7.1.1 Level of understanding of the framework

The participants commented that the framework has a clear and easy to understand structure. They state the high level of understanding of the framework

9.7.1.2 Level of termination of the framework

Participants consider that all the terminology and structure of the framework are explained properly. They suggested that the documentation of the framework should include the correspondent definitions of the necessary terms to understand the framework. They also suggested a deeper explanation of the technological context of the motivation framework.

9.7.1.3 Logic flow of the proposed framework

The framework has a good thread which connects all the concepts and actors involved. They participants found the logic flow appropriate and reasonable.

9.7.1.4 Comments and suggestions on areas that need improvement

The interviewees of the validation process suggested that the IoT service provider should be more involved in the process of identification of opportunities for improvement of the construction company. Also, in addition to the feasibility analysis, the framework should propose follow-up and measurement of KPIs during the implementation.

9.7.1.5 Usefulness of the framework

All the participants consider this framework useful, especially for an initial implementation. In addition, one of the participants highlighted that this framework can also be applied outside the construction industry.

9.7.2 Changes and final comments on the framework

The feedback received during the validation process has been incorporated into the framework. Based on this feedback, a list of objective and subjective KPIs were added to the framework to follow-up its implementation. Also, it was suggested that the government should consider subsiding the implementation of smart devices in small companies.

The following questions were raised from the validation process. These questions are proposed for future research in this field:

- In what phases of the construction process is more convenient to implement smart devices?
- Should the government subsidise small companies to implement smart devices or prioritise large companies in this implementation?
- Which stakeholders of the construction industries benefit most of the implementation of smart devices?

9.8 Summary

This chapter has discussed the development of a strategic framework for incentive and perform the implementation of smart devices in the Construction industry. The fragmented nature in the construction industry and its fragmented, multi-participant, project-based supply chain has provided scenario where improvement through the implementation of IoT is necessary if not imminent. The UK government has already started its Digital Built Britain strategy to embed the IoT into cities and industry.

The proposed framework consists of two sub-frameworks. Firstly, a framework for persuading construction organisations to adopt smart devices into their processes which is called Persuasion-Decision framework. Secondly, a framework for Implementing smart devices into the construction projects which is called Implementation-confirmation framework.

The Persuasion-decision framework describes actions to incentive the future adoption of smart devices on two contexts: The organisational context and the external environment context. The Implementation-confirmation framework describes a systematic and strategic process to implement smart devices into the organisation's projects once the organisation has decided to adopt the IoT paradigm.

The proposed framework is a useful tool for the government, the organisations' decision makers, and technology consultants to strategically implement smart devices into their processes. In doing so, this chapter addressed objective 6 of the current investigation, which is "to develop and validate a strategic framework for the implementation of smart devices in the construction industry".

This chapter has addressed the sixth and final research objective of this study which is develop and validate a strategic framework for implementing smart devices in the construction sector. There are no research questions attached to this objective. The following chapter presents the conclusions and recommendations of this investigation.

Chapter 10: Conclusions and recommendations

10.1 Introduction

This thesis now turns to a discussion of the conclusions and recommendations based on the findings of the investigation. The research process is recapitulated, and the key findings, conclusions and recommendations are addressed. The recommendations for the body of knowledge and body of practice are explained, and opportunities for future work in this field are highlighted. The section below addresses the research process of this study.

10.2 Research process

The overall aim of this investigation is to develop a strategic framework for implementing smart devices in the construction industry. In order to achieve this aim the following objectives were identified:

1. To establish a clear definition of the concept “smart device”
2. To explore the adoption of smart devices in construction projects
3. To investigate the drivers for implementing smart devices in the construction sector
4. To explore the challenges for implementing smart devices in the construction sector.
5. To explore the critical factors for a successful implementation of smart devices in the construction industry.
6. To develop and validate a strategic framework for the implementation of smart devices and the paradigm of the Internet of Things (IoT) in the Construction industry.

This investigation followed a pragmatic philosophy to answer the research fulfilled the research objectives, a qualitative approach to collect and analyse data was implemented. Thirty-nine semi-structured interviews were made to professional of the construction industries of the DR and UK. Interviews were audio recorded and then transcribed. As part of the analysis of the interviews, thematic analysis was employed. The data analysis included a literature review to find data which corroborate or refute the findings from the interviews; this served as a triangulation technique. Content analysis was used to analyse the review of the literature.

The following section discusses the key findings for each research objective and the conclusions drawn from these findings.

10.3 Contribution to the current state of knowledge

The development of this investigation has generated theoretical and methodological contributions to knowledge which are address in this section. First the methodological contribution to knowledge are explained followed by the theoretical contribution

10.3.1 Methodological contribution

A novel methodology for data collection is proposed for academia. Semi-structured interviews were invented decades ago before all the technology associated with smart devices came to be. This investigation proposes to integrate smart devices into academia and data collection methodologies.

The problem with qualitative data collection, particularly, interviews, is that it requires the elaboration of a set of questions which need to be asked all together, usually on the same day. All the interviewees get asked the same questions. Nowadays people rely on video calls to contact people who are far from us. Hence, researchers are already embedding technology in their research projects. The problem arises when after processing the data new question are found, since this would require to do another round of data collection.

This research recommends a new methodology in which the interviewees are contacted through a chat Application (i.e., WhatsApp), then the questions are sent to them, and they send a voice note answering the questions. If a new question arises then the interviewees can be contacted again; An additional question can be sent and answered from them.

10.3.2 Theoretical contribution

The theoretical contributions of this research are grouped and presented by research objective. Each objective contains its own research questions which are also addressed. Six research objectives are presented below:

10.3.2.1 Research Objective 1: Definition of smart devices

This objective was addressed in chapter 4 and has one research question which is:

Research question 1: What is a Smart device?

The work done during this research process explained the concept of smart device within the paradigm of the IoT. This concept has been under development for the last decade, and due to the growing complexity of these devices and the fast-changing and evolving research community, there was a need for a precise definition of this term. The concept developed in this investigation is modular and scalable; this means that new key features might be added depending on the changing characteristics of the global market and state of technology.

This study proposes three key features that make a device or object “smart”, namely Autonomy, context-awareness, connectivity. It can be inferred that almost any device or object can become smart by adding these features.

As an example, if a chair gets a sensor (context-awareness) for detecting when someone is sitting, then it processes that information (autonomous computing) and sends it through a network (device connectivity), at that moment we can call that chair “Smart”. Moreover, by using a similar approach with other devices, we can easily implement the paradigm of IoT in the industry and homes.

10.3.2.2 Research Objective 2: Adoption of smart devices in the Construction industry

This research objective was addressed in chapter 5 and has two research questions:

Research question 2: What smart devices are used in the construction industry?

Chapter 5 contains the findings for this research question. It was found that the smart devices used in the construction industry are: Smartphones, Tablets, Wearable devices, Unmanned devices, Smart boards, Sonar surface, Existing equipment integrated with GPS tracking devices, and security cameras. The most used devices were smartphones and tablets.

Research question 3: What are the utilisations given to smart devices in construction projects?

Chapter 5 also discusses the results for this research question. The study showed the utilisations of smart devices in the construction industry of the Dominican Republic

(DR) and the United Kingdom (UK), namely, data capture and display, communication, project management, contextual data request, material management and smart metering. Although the themes raised from the qualitative analysis were identical, a different level of implementation was shown by each industry. The categories used to catalogue the utilisation give to smart devices played a crucial role in the elaboration of the strategic framework explained in chapter 10.

Consultants in the Construction industry may provide solutions to construction organisations based on the data shown in this investigation. Researchers can use this research as an insight into the implementation of smart devices in the construction industry.

10.3.2.3 Research Objective 3: Drivers for implementing smart devices in the Construction industry

This research objective was addressed in chapter 6 and has one research question:

Research question 4: What are the drivers that have fuelled the implementation of smart devices in construction projects?

This investigation has found the main drivers for implementing smart devices in the construction sector. They were grouped into two key groups, namely, internal and external drivers. Internal drivers directly affect the workforce of construction companies, they are more individual-oriented and on focus for the internal side of the company, whereas external drivers are particularly oriented towards the decision makers and external factors of the company.

Internal drivers were: productivity, mobility, communication, management and procurement, and health and safety whereas external drivers were, environmental protection, corporate transparency, competitive advantage, and stakeholder satisfaction.

This study noticed a difference between the DR and UK construction sectors. Health and safety and competitive advantage were relevant drivers only for the UK. Whereas stakeholder satisfaction was a particular driver only in the DR. There is mutual agreement between DR and UK on productivity, mobility and communication being key drivers for the implementation of smart devices.

10.3.2.4 Research Objective 4: Challenges for implementing smart devices in the construction industry

This research objective was addressed in chapter 7 and has one research question:

Research question 5: What are the challenges that the construction industry faces for implementing smart devices?

This investigation has found the main challenges for implementing smart devices in the construction sector. They were grouped into three key groups, namely, economic, cultural and technological challenges. Economic challenges present cost and company size. These findings are thoroughly discussed in Chapter 7.

Economic challenge was the most mentioned challenge in both the DR and UK data collection. It is definitely a challenge to consider when implementing smart devices. Also, was organisational culture and training and development of employees. We noticed that all the challenges manifested differently in the UK and DR construction industry. In each country interviewees mentioned aspects that related more their work context.

10.3.2.5 Research Objective 5: Critical Success Factors (CSFs) for implementing smart devices in the Construction industry

This research objective was addressed in chapter 8 and has one research question:

Research question 6: What are the CSFs for implementing smart devices in the construction?

The investigation has identified seven CSFs that can contribute to the adoption and implementation of smart devices in the Construction industry:

- Leadership
- Training and development
- Organisational culture
- Technology awareness
- Cost
- Company size
- Usability

Chapter 8 showed a similar tendency in the rate of the importance of the CSF from the data collected in the DR and the UK. Both countries showed having similar considerations regarding the level of importance of the CSFs for implementing smart devices in the Construction industry.

The key factors obtained in this study relate differently to the stakeholders of the construction industry. From an organisation's perspective, it is recommended to consider all the CSFs previously described. To develop the right policies, the government should develop case studies which provide a quantitative result for the efficiency behind the implementation of the IoT in construction projects. Then it would be positive to develop the right policies which promote the right implementation of the IoT in a construction project. Government policies play a crucial role in incentivising or even forcing companies to move towards a more technological environment with a deeper implementation of the IoT. As an initial step, government policy can motivate both public and private sectors to implement smart devices in construction projects.

Policymakers should also consider variables such as company size, usability, cost of implementation and interoperability when designing and enforcing a plan for implementation since these variables play a delicate role in the successful implementation of smart devices.

The main role of technology consultants is to provide advice to companies about the implementation and integration of technology for their projects. Technologies such as BIM require employees to go through rigorous training in order to achieve a beneficial development in the workplace. Consultants should be aware of the latest case studies in the industry and the best solutions to implement based on the company size.

Construction companies should consider leadership as on of the main CSFs for implementing smart devices in their projects. In the United Kingdom for example, according to Farmer (2016) the construction industry has a highly fragmented nature of leadership and decision making which translates into a lack of collective responsibility for change. Companies adopting IoT devices should provide and enable knowledge capture and sharing, resulting in the creation of new explicit knowledge.

10.3.2.6 Research Objective 6: Framework for implementing smart devices in the Construction industry.

This research objective was addressed in chapter 9 and has no research question. Instead its outcome is a conceptual framework for implementing smart device in the construction industry.

This investigation was by nature exploratory aiming to find the means required to implement smart devices in construction projects. The qualitative data analysis revealed two dimensions in the process of adopting smart devices. First, there is the persuasion of the decision makers, and then there is the implementation of the IoT system. The collected data allowed the research team to develop two frameworks, one is called persuasion framework and intends to create awareness, increase leadership and change the culture of companies which are not sure of implementing smart devices. Secondly, we developed an implementation framework, which is designed for companies who have already decided to implement smart devices and require a strategy for doing so successfully.

The validation process consisted of semi-structured interviews with professionals of the construction industry with more than 5 years of experience. This process helped to strengthen the proposed framework.

10.4 Conclusions

Based on the findings of this investigation, the following conclusions have been drawn:

10.4.1 Concept of smart device

This investigation suggests that a smart device can be mobile and can be user-oriented but is not a must for a device to have any of these features. By defining a clear concept of smart device this investigation offered clarity and transparency between technology consultants, researchers and companies from all industries which intend to incorporate the paradigm of the IoT. The concept offered in this research can be used to create an online dataset which contain all the smart devices available for purchase.

10.4.2 Government culture

This research has seen two types of governments. Firstly, the DR government, which is passive, and follows trends which are already proven by the private sector and have demonstrated an increase in productivity by either cost reduction or time saving. Secondly, the UK government, which is active and promotes the implementation of new paradigms such as the IoT or BIM.

10.4.3 Organisational culture

The culture of an organisation is crucial for technological innovation. As discussed in chapter 7, there are several key elements that relate to the culture of the organisation, namely, leadership, organisational culture, training and development and distraction of employees. Chapter 7 also mentions project location as a cultural challenge, although this factor is mentioned as an external cultural aspects that can affect a construction project. Cultural factors have been more suggested in the data collection than economic factors and could be considered as more important than the cost of implementation or company size.

This investigation has found through the data collection and analysis that an appropriate organisational culture for harvesting innovation is necessary for a successful implementation of smart devices. The literature has shown that such culture is called “innovation culture” and has the following features: (1) Corporate management should be willing to take risks, (2) the participation of all members of the organisation should be requested, (3) creativity should be stimulated, (4) there should be shared responsibility. Additionally, Canalejo (1995) suggested the following values for firms to adopt an innovative organisational culture: client-orientation, commitment towards the objective, challenge and initiative, exemplary behaviour, team work and permanent improvement.

10.4.4 Distraction of employees

This investigation proposes a set of rules for identifying when a distraction of employees is generated by a smart device distract in the construction industry. A distraction generated from a smart device has to comply with the following rules: (1) It has to be experienced by a member of the organisation; (2) It is an intrusion to a primary task; (3) It generates discontinuity to the task; (4) It can be externally or internally initiated; (5) It is situated in a construction project or office setting; And (6) it is mediated by a smart devices.

10.4.5 Environmental protection

Smart devices play an important role in Environmental protection. It appears that the most noticeable contribution of smart devices to environment protection is reducing the paperwork in projects. The literature showed several examples of companies which implemented paperless projects (Coddington, 2012; Hogan, Ghanem and El-Gafy, 2015).

10.4.6 Pervasive Augmented Reality

The implementation of Pervasive Augmented Reality (PAR) is promising since it could bring error reduction and consequently cost reduction in the construction industry by providing continued assistance and context-aware suggestion to the work-force. Nevertheless, the cost of the technology is a crucial limitation for its implementation, as well as existing hardware issues that might need to be overcome before actual implementation. The main drivers for the implementation of PAR are error reduction, cost reduction, and continued assistance; whereas the main challenges are cost, hardware issues and development of applications.

The implementation of this technology looks like the definite future for the construction industry, and although some present limitations might slow down its implementation, the possible applications are promising, such as visualisation of technical information on the job site, visualisation of a spatial model for design and marketing.

10.5 Recommendations

10.5.1 Recommendations for academic and researchers

The amount of IoT devices worldwide accounts for 26.66 billion (Statista, 2019) and is expected to be 30.73 in 2020, and 75.44 in 2025 (Statista, 2019). This study has found that research firms as Gartner and Allied Business Intelligence (ABI) were very accurate years ago in the prediction of these trends. Gartner research firm estimated that IoT will connect close to 26 billion devices by 2020 (Gartner, 2014). Allied Business Intelligence (ABI) Research estimated the number will be more than 30 billion by 2020 (Allied Business Intelligence, 2013). Consequently, we recommend their future use for forecasting statistics.

It is recommended to develop a case study of successful implementation which contains at least the following three outcomes: a cost-benefit analysis based on company size, interoperability challenges and opportunities, feedback of users regarding usability and user-interface. This new creation of explicit knowledge can be used as a tool to incentivise the decision makers of the industry within the private sector to implement smart devices since they are driven by profit and would be willing to implement a solution if it promises an enhancement in the efficiency of their company. the creation and transfer of explicit knowledge through a case study should be structured, codified and digitised; providing documented information that can facilitate implementation.

10.5.2 Recommendations for construction companies

The social and technological context surrounding the project location should be considered prior to the implementation of smart devices. Regarding the technological context, a project location might not have good internet access, and this might require a higher expenditure for implementing smart devices. Finally, regarding the social context, a project location might not be safe enough for workers to carry expensive devices with them; this might difficult or make unviable the implementation of smart devices.

Organisational culture has been found (see chapter 8) as a CSF for implementing smart devices in the construction industry. Moreover, it was one of the CSF most mentioned by interviewees during the data collection process. The literature on organisational culture provided an insight of what characteristics has an organisational culture prompt to be innovative in terms of technology. For a company to generate a change in its organisational culture it needs to become more: willing to take risks, open to the participation of all members of the company, creative and client-oriented. These actions are initially suggested to construction companies but can be adopted in any industry.

10.5.3 Recommendations for the government

For a government that acknowledges the benefits of implementing smart devices in the construction industry, we recommend implementing regulations to push large organisations to implement smart devices in their projects, and to subsidise this implementation in small and micro companies. The strategic framework proposed in chapter 9 can be used by the government to develop guidelines or regulations for implementing smart devices. The feasibility analysis proposed in section 9.6.2.3 can be used to evaluate the scenarios when a construction organisation should or must implement smart devices.

10.6 Future research

During the validation process of the strategic framework presented in Chapter 10, interviewees asked questions which still need to be addressed. Although this research explains the drivers and challenges to implement smart devices in the construction industry, future research should be done on which stages of the construction industry are more benefited from the implementation of smart devices.

To contribute with this future research objective, we suggest using Succar's project lifecycle phases and sub-phases (Succar, 2009) to perform a multivariable analysis on the most benefited phases from the implementation of smart devices. This investigation addressed the motivations, barriers and critical success factors for implementing smart devices during the construction phase. However, the design phase and operations phase should be explored in more detail.

Table 10.1: Project lifecycle phases and sub-phases
Adapted from Succar (2009).

Design phase		Construction phase		Operations phase	
D1	Conceptualisation, programming and cost planning	C1	Construction planning and construction detailing	O1	Occupancy and operations
D2	Architectural, structural and systems design	C2	Construction, manufacturing and procurement	O2	Asset management and facility maintenance
D3	Analysis, detailing, coordination and specification	C3	Commissioning, as-built and handover	O3	Decommissioning and major re-programming

Future work in this field should be oriented towards gathering and comparing the CSFs for implementing smart devices in other countries with a different socio-economic situation and developing case studies of successful implementation of smart devices in construction projects. Also, the CSFs presented in this investigation can be part of a large strategic framework for implementing smart devices in construction projects. Future research should expand the existing knowledge and understanding of the internal structure of the strongest Latin America economies based on the GDP per capita.

Prior to this research, there was no background to which were the drivers, challenges and CSFs for implementing smart devices in the construction industry. This investigation now highlights what those aspects are. Future research should focus on showing the difference between the cultural aspects of distinct countries based on cultural variables such as power - distance, uncertainty – acceptance, collectivism and individualism.

This investigation has found distraction of employee as a challenge to consider for implementing smart devices (See Chapter 7). This is corroborated by McBride (2015) which states that mobile smart devices can cause distraction by interrupting primary tasks of employees and creating discontinuity in the work labours. Further studies should consider analysing the distraction generated by smart devices in the construction industry.

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Appendices

This section shows the appendices for this investigation. Five Appendices are presented showing the following:

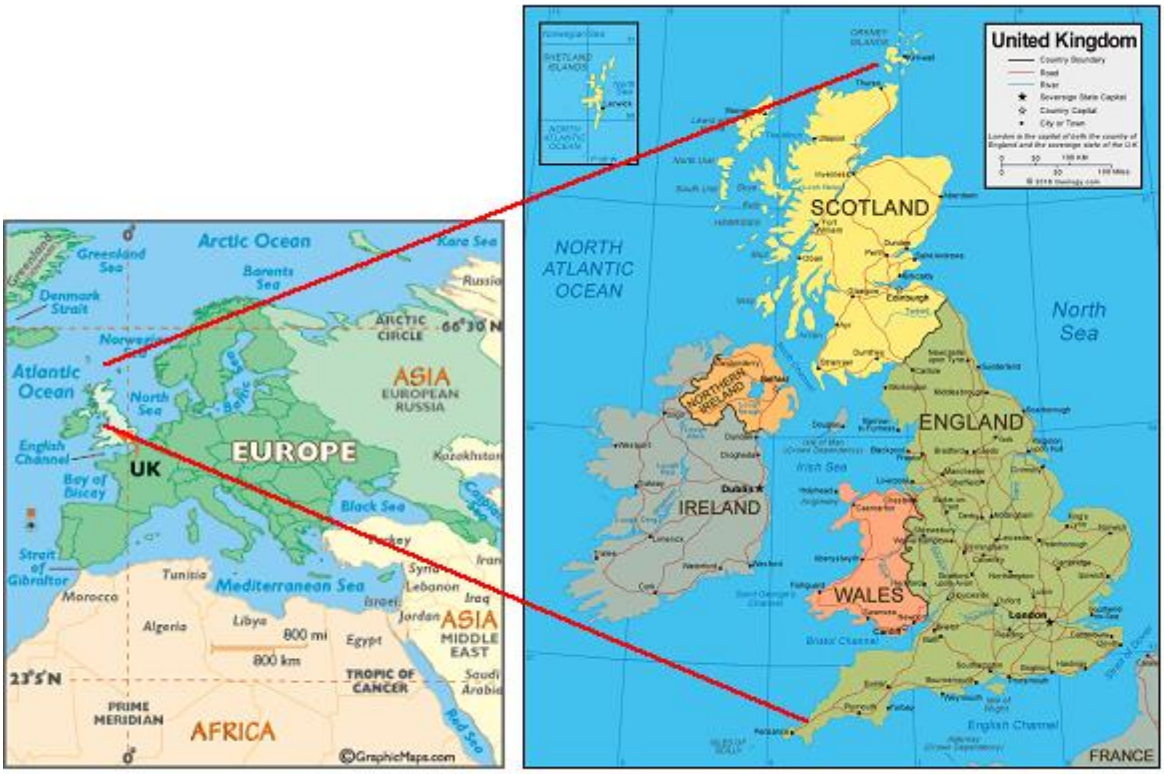
- Appendix A: Localisation and Map of the Dominican Republic
- Appendix B: Localisation and Map of the United Kingdom
- Appendix C: Interview protocol for pilot study
- Appendix D: Interview protocol for main data collection
- Appendix E: Protocol for validation of strategic framework
- Appendix F: Previous versions of the developed strategic framework

Appendix A: Localisation and map of the Dominican Republic

This appendix shows a map of the Dominican Republic and its localisation in the American Continent.

Appendix B: Localisation and map of the United Kingdom

This appendix shows a map of the United Kingdom and its localisation in the European continent.



Appendix C: Interview protocol for pilot study

Date	
Time of interview	
Name of organisation	
Organisation’s industry sector	

	Name of Interviewee	…………….………………………………………
	Position of Interviewee	…………….………………………………………
	Organisation’s total employee size	…………….………………………………………
	• Please kindly tell me a little about what your current job role is in the organisation?	
	• Given your role in this organisation, please explain what does “digitalisation of construction” mean to you and your organisation? (e.g. smart devices, BIM, VR, AR, etc.)	
	• Do you think your organisation is committed to embed advanced technologies to enhance construction productivity?	
	• How is your organisation’s top management commitment towards adopting new technologies? o Do people in your organisation utilise ‘smart devices’? o Does your organisation provide ‘smart devices’ to their employees	
	• Please kindly tell me the most common utilisations given to ‘smart devices’ by you or others employees in the construction industry.	
The next few questions will focus on key drivers for implementing ‘smart devices’ in construction projects		
	• Can you describe the key drivers that have fuelled the need for implementing ‘smart technologies’ initiatives in your organisation?	
The next few questions will focus on main challenges organisations face in implementing key ‘smart devices’ *initiative.*		
	• From the job role and responsibilities that you perform in this organisation, please, enlighten me on the main challenges your organisation faces in implementing ‘smart devices’?	

The next few questions will focus on key 'smart technologies' that have been implemented or planning to implement in your organisation in the next 5 years.	
	• From the job role and responsibilities that you perform in this organisation, please, describe key technologies when considering the implementation of ''smart devices': • Which 'smart technologies' are currently being implemented in your organisation • Which 'smart technologies' are planned to implement in your organisation in the next 5 years?
The next question will focus on the impact of key 'smart devices' on organisational competitiveness.	
	• Given your job roles and responsibility, kindly explain how the implementation of 'smart devices' have contributed to your organisation's competitiveness?
The next question will focus on the Critical success factor for the implementation of smart devices in the construction industry	
	• What are the critical factors for a successful implementation of 'smart devices in the construction industry?
The next question will focus on the need of a guidance document for implementing smart devices in construction project	
	• What is your opinion about the existence of a set of guidelines or guidance document for implementing 'smart devices' in construction projects

Thank you for your views on the above questions. I would also like to thank you for the time you have dedicated to this research. If you are interested to know the outcome of this research, it would be my pleasure to share it with you.

Appendix D: Interview protocol for Main data collection

This protocol describes the changes made to the data collection procedures, based on the pilot study performed from December 2016 to January 2017.

The pilot study consisted of 15 semi-structured interviews to professionals with more than one year of experience in the construction industry of the Dominican Republic. The demographics are shown below:

No.	Profession	Position	Company Code	Gender	Company size	Sector	Experience in construction (years)	Place of interview	Interview method	Date of Interview	Experience (years)
1	Civil engineer	Resident engineer	DR-01	Male	Small	Private	More than 3	Santo Domingo	Face-to-face	21/12/2016	3
2	Civil engineer	Resident engineer	DR-02	Male	Large	Public	More than 30	Santo Domingo	Face-to-face	21/12/2016	30
3	Civil engineer	Director	DR-03	Male	Micro	Private	More than 2	Santo Domingo	Face-to-face	22/12/2016	2
4	Civil engineer	Director	DR-04	Male	Micro	Private	More than 12	Santo Domingo	Face-to-face	23/12/2016	12
5	Architect	BIM manager	DR-05	Male	Small	Private	More than 4	Santo Domingo	Face-to-face	23/12/2016	4
6	Civil engineer	Project manager	DR-06	Male	Medium	Private	More than 5	Santo Domingo	Face-to-face	27/12/2016	5
7	Civil engineer	Project manager	DR-07	Female	Large	Public	More than 6	Santo Domingo	Face-to-face	30/12/2016	6
8	Civil engineer	Project manager	DR-08	Female	Micro	Private	More than 4	Santo Domingo	Face-to-face	30/12/2016	4
9	Civil engineer	Resident engineer	DR-05	Male	Small	Private	More than 9	Santo Domingo	Face-to-face	02/01/2017	9
10	Civil engineer	Resident engineer	DR-05	Male	Small	Private	More than 6	Santo Domingo	Face-to-face	02/01/2017	6
11	Architect	Drawings coordinator	DR-09	Female	Large	Public	More than 4	Santo Domingo	Face-to-face	02/01/2017	4
12	Architect	Project designer	DR-10	Female	Medium	Private	More than 4	Santo Domingo	Face-to-face	05/01/2017	4
13	Civil engineer	Project manager	DR-10	Male	Medium	Private	More than 5	Santo Domingo	Face-to-face	06/01/2017	5
14	Architect	Project manager	DR-10	Female	Medium	Private	More than 5	Santo Domingo	Face-to-face	06/01/2017	5
15	Architect	Project manager	DR-10	Female	Medium	Private	More than 10	Santo Domingo	Face-to-face	06/01/2017	10

The experience of the participants adds up to 109 years. The participants with the least experience have more than 2 years of experience, whereas the participants with the most experience have more than 30 years.

Based on the experience gained during the pilot study, the following changes were made to the main data collection.

Modifications in interview protocol

- The format and order of the interview questions was changed. The questions were properly sectioned and numbered.
- The order of the questions was updated because it was found that questions about the utilisation of smart devices leaded to questions of the organisation’s competitiveness which were located after questions about main drivers and challenges for implementing smart devices.

- Changed the term ‘smart technologies’ for ‘technologies related to smart devices’

New coding for files used in Nvivo

The code used for the word files inserted in Nvivo has been updated.

During the pilot study, the following code was used:

DATA COLLECTION NUMBER – INTERVIEW – NUMBER – PROFESSION

5. Data collection number: 1DC, 2DC
6. Interview: INV
7. Number: 001 – 015
8. Profession: ENG, ARQ

This code had four terms. Since all the files are interviews, then the second term will always be interview, hence there will not be any distinction between the “INV” term in 1DC-**INV**-001-ENG and 1DC-**INV**-002-ENG.

The new code is the following:

DATA COLLECTION NUMBER – COUNTRY – NUMBER – PROFESSION

5. Data collection number: 1DC, 2DC
6. Country: DR, UK
7. Number: 001 – 025
8. Profession: ENG, ARQ

This new coding system will allow the files to be sorted in a more meaningful way for the project.

Interview Questions

Demographics

Date:

Time of interview:

Name of organisation:

Position of interviewee:

Years of experience of interviewee:

Section 1: Job role and digitalisation of information

- Please kindly tell me a little about what your current job role is in the organisation?
- Given your role in this organisation, please explain the status of “digitalisation of construction” within this organisation or How this organisation handles paperwork?

Section 2: Utilisation of smart devices and organisational competitiveness

- How is your organisation’s top management commitment towards adopting new technologies?
    a. Do people in your organisation utilise ‘smart devices’?
    b. Does your organisation provide ‘smart devices’ to their employees?
- Please kindly tell me the most common utilisations given to ‘smart devices’ by you or others employees in the construction industry.
- Given your job roles and responsibility, kindly explain how the implementation of ‘smart devices’ have contributed to your organisation’s competitiveness?

Section 3: Implementation of technologies related to smart devices in the present and future

- From the job role and responsibilities that you perform in this organisation, please, describe key technologies when considering the implementation of ‘‘smart devices’:
- Which technologies related to smart devices are currently being implemented in your organisation
- Which technologies related to smart devices are planned to implement in your organisation in the next 5 years?

Section 4: Drivers and challenges for implementing smart devices

- Can you describe the key drivers that have fuelled the need for implementing ‘smart technologies’ initiatives in your organisation?
- From the job role and responsibilities that you perform in this organisation, please, enlighten me on the main challenges your organisation faces in implementing ‘smart devices’?

Section 5: Critical factors for successfully implementing smart devices in the construction industry

- What are the critical factors for a successful implementation of ‘smart devices in the construction industry?

Section 6: Need for guidance document for implementing smart devices in construction projects

- What is your opinion about the existence of a set of guidelines or guidance document for implementing ‘smart devices’ in construction projects

Appendix E: Protocol for validation of strategic framework

Introduction to the interview

The aim of this validation interview is to refine and validate the proposed framework in terms of clarity, information flow and contents in terms of generic and detailed components. The proposed framework is a part of doctoral research study that sought to develop a strategic framework for adopting and integrating smart devices in the construction industry. The proposed framework is based on the findings of literature review and 39 semi-structured interviews.

This interview aims to gather your responses which will help the researcher to validate the framework that will subsequently be applied for the effective implementation of smart devices in construction organisations. This cannot be effectively developed without your participation; therefore, you are requested to participate in the interview. This interview is estimated to take about 15 minutes.

In order to protect your confidentiality, privacy, dignity and anonymity, your answers will be attached with a unique code that will only be understood and accessed by the researcher. This will be stored in a password-protected computer that only the researcher has access to. Finally, any data provided by you will be destroyed once the degree is achieved. The project has ethical approval for the study protocol from the University of Wolverhampton, which provides further assurance.

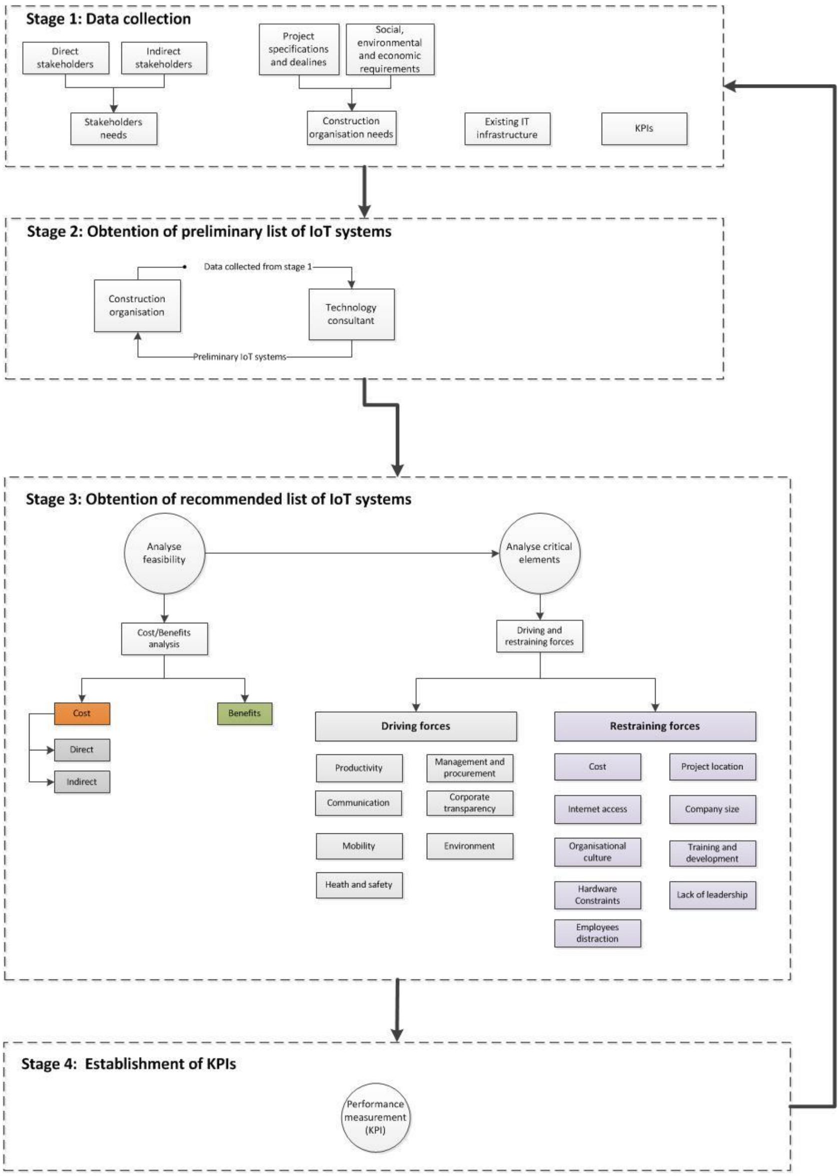
Questions:

- What is your opinion on the level of understanding of the proposed framework?
- What is your opinion regarding the overall level of completeness of the proposed framework?
- What is your opinion regarding the logic flow of the proposed framework?
- Do you have further comments/suggestions regarding any areas that need to be improved/included/deleted within the proposed framework?
- How would you describe the usefulness of this framework for companies in the construction industry?

Appendix F: Previous versions of strategic framework

This section presents previous versions of the strategic framework proposed in this study. Prior to the validation process of the framework various versions were proposed. A review process with many updates was done until the final version was presented in chapter 10 of this thesis.

The following diagram shows a 4-stages framework previously proposed:



The following diagram shows an input-output framework previously developed in this investigation: