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Strategic framework for implementing smart devices in the construction industry

Manuel Silverio-Fernández, Suresh Renukappa, and Subashini Suresh
Faculty of Science and Engineering,
University of Wolverhampton, UK

Suresh.Renukappa@wlv.ac.uk

Abstract

Purpose: The decentralisation of information and high rate of mobile content access in the construction industry provides an ideal scenario for improvement of processes via the implementation of the paradigm of the Internet of Things (IoT). Smart devices are considered as the objects interconnected in the IoT; therefore they play a fundamental role in the digital transformation of the construction industry. Currently, there is a lack of guidelines regarding the implementation of smart devices for digitalisation in the construction industry. Consequently, this paper intends to provide a set of guidelines for implementing smart devices in the construction industry

Design/methodology/approach: An empirical study was performed in the United Kingdom (UK) and the Dominican Republic (DR). Following a systematic approach, qualitative data collection and analysis was performed based on semi-structured interviews involving professionals from construction companies in the UK and the DR. Interviews were recorded and subsequently transcribed using and exported to the software NVivo where it was used to find common thematic nodes across all interviews.

Findings: The findings encompass drivers, challenges and Critical Success Factors (CSFs) for implementing smart devices in construction project. For both countries the top five CSFs were Leadership, Staff training, culture, technology awareness and cost of implementation. These findings were used to develop a strategic framework for implementing smart devices in construction companies. The framework stablishes the actors, elements and actions to be considered by construction companies when implementing smart devices.

Originality/value: The paper provides a richer insight into the understanding and awareness of implementing smart devices. A strategic framework for implementing smart devices in the construction industry and providing guidelines for adopting smart devices in construction projects was developed and validated. This study provides a better understanding of the key factors to be considered by construction companies when embedding smart devices into their projects.

Keywords: smart devices; construction industry; AEC sector; Internet of Things

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1 Introduction

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. By 2019, the number of IoT devices was 26.66 billion, and is expected to be 75.44 in 2025 (Statista, 2019). Nowadays, the construction industry relies on smart devices and data connectivity for its operations, and a set of guidelines for implementing smart devices is seen as a helpful asset by professionals of the industry.

Crotty (2013) highlighted two key strategic challenges for the construction industry, namely, inability to complete projects predictability and low level of profitability. Crotty (2013) considers these issues as of first order of importance since it is vital for the survival of construction organisations. Other challenges such as sustainability, productivity, collaboration and safety as treated by Crotty (2013) as second order issues, since they are not vital to the survival of construction organisations. Nevertheless, considering the recent global challenges of sustainability and climate change, a good practice would be to address all challenges in an integral and collaborative manner. The solution shown by Crotty (2013) consisted of improving communications techniques and information exchange in the construction industry. To achieve this, it is suggested to improve nature and quality of information 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 been considered to have a multi-participant, project-based supply chain (Andresen *et al.*, 2002). A 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. The same study shows that the construction industry has the highest degree of decentralisation of information among five different industries and the highest amount of external collaboration; this results in a high rate of subcontracting and interaction between workers. This fragmented nature in the construction industry incentivises the government, researchers and software developers to create innovative solutions based on the IoT to increase productivity and fluid communication among stakeholders within the industry.

Previous studies have shown the status of adoption of smart devices in the construction industry, Liu et al. (2017) found the key application areas for using smart devices in the New Zealand Construction industry. Silverio-Fernandez *et al.* (2018b) addresses the key uses of smart devices. Overall, smart devices are shown to have a mostly positive impact on the construction jobsite operations (Azhar and Cox, 2015). No studies are done on critical success factors and drivers for implementing smart devices in the construction industry.

Although various studies have provided guidelines of implementation of smart devices, they do not address particularly the construction industry. Therefore, the core objective of this paper is to present a strategic framework for implementing smart devices in the construction companies. The developed framework provides a better understanding of the driving and restraining forces for implementing smart devices in the construction industry.

Research Gap

For this research, DR and UK construction industry were considered because of its environmental, social and economic impact on the wider society. This investigation performs a spatial cross-national comparison between a developed country and a developing country. These two countries have different socio-economic situations and will provide a wider frame regarding the construction industry. The results will provide a wider insight into the strategic points for a successful implementation of smart devices in different socio-economic environments.

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.

From the perspective of the UK, embedding smart devices into construction is an important initiative for the UK government. UK government's Industry Strategy and Digital Built Britain strategy (HM Government, 2015 and 2017) 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.

The 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 to professionals within the field of Architecture Engineering and Construction (AEC) 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 to 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 America economy, interacting with major players such as México and Brazil, which according to Hofman *et al.* (2017) have the biggest 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 the one 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. However, 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. Therefore, it is necessary to develop strategies for embedding new technologies such as smart devices and the paradigm of the IoT within the construction industry.

This paper presents an exploration into the implementation of smart devices in the construction industry and a strategic framework built to support said implementation. A key motivation for performing this research is that a strategic plan of action for implementing smart devices during the construction stage of a construction project might have a very positive impact for the construction industry (See section 2). This paper presents a strategic framework to facilitate the future implementation of smart devices. To achieve this, first, the drivers, challenges and Critical Success Factors (CSFs) for implementing smart devices in the construction industry of the United Kingdom (UK) and the Dominican Republic (DR) are discussed. Finally, conclusions and recommendations a drawn in section 6.

2 Literature Review

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.

The IoT interconnects uniquely identifiable context-aware devices (Miller, 2015). These context-aware objects are also known as smart devices (Silverio-Fernández *et al.*, 2018a). Ultimately, the IoT enables any work environment with automated machines and metrics which improve efficiency and prevents errors. Smart devices play a crucial role in the IoT as they can be considered as the “Things” or “objects” within the network of interconnected devices known as the IoT (Stojkoska and Trivodaliev, 2017).

Smart devices are objects capable of communication and computation which range from simple sensor nodes to home appliances and smartphones. Following the concepts proposed by Stojkoska and Trivodaliev (2017) and (Silverio-Fernández *et al.*, 2018b) this paper considers smart devices as the objects present in the pervasive network of the IoT. Some authors also use other terms for refering to smart devices, 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.

According to Liu et al. (2017) the application areas for using smart devices in the New Zealand Construction Industry are: Photos, Health and safety reporting, timekeeping, Requests For Information (RFIs), Progress Tracking, change orders, communication and punch list. Similarly, Silverio-Fernandez *et al.*(2018b) addresses the key uses of smart devices as capture and displaying data, data exchange, site supervision, contextual data request, smart metering and material management. Although workers in construction projects are benefiting from the use of smart devices. The respondents of said investigations embedded smart devices into their daily operation empirically, without following a strategic approach.

Another important aspect for implementing smart devices in construction projects is the challenges of implementation. Azhar and Cox (2015) presents the following challenges that impact the widespread adoption of mobile solutions: cost of training, hardware maintenance cost, software licensing fee connectivity issues and interoperability issues. Although these issues are presented from the perspective of mobile solutions, they are an important background to consider for the implementation of smart devices.

Smart devices are shown to have a mostly positive impact on the construction jobsite operations (Azhar and Cox, 2015). There are multiple studies which have provided guidelines on the implementation of smart devices, for example, Souppaya and Scarfone (2013) provided a set of guidelines for managing the security of mobile devices, also Bregman and Korman (2009) created a universal implementation model for smart homes. Previous studies which focus on the construction industry mainly address the existing implementation of smart devices rather than providing guidelines for further implementation. The literature shows pieces of information regarding the implementation of smart devices, nevertheless, a strategic plan of action might have a very positive impact for the construction industry. Consequently, this paper presents a strategic framework which both industry and academia can use as a set of guidelines for implementing smart devices.

3 Research Methodology

A qualitative research approach was selected following the theory of Creswell and Poth (2017). Ethics process was followed and approval was obtained. The questions necessary to fulfil this research were asked in semi-structured interviews. This study required in-depth data about the phenomenon under investigation, such data can be extracted from the participants' experience through semi-structured interviews, however it cannot be obtained from structured questionnaires, participant observation or analysis of the literature (McInstosh and Morse, 2015).

Fourteen semi-structured interviews were performed in the UK among ten companies from the construction sector, enquiring about: utilisation of smart devices in construction projects, drivers, challenges and critical factors for a successful implementation of smart devices. A set of twenty-five semi-structured interviews was also performed in the DR with the same questions. The sampling technique in both countries 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). The sample size was based on data saturation theory as explained by Mason (2010) and Creswell and Poth (2017). 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.

Interviews were recorded using smart phone with the app "Easy voice recorder". The digital voice recording was transcribed using MS Word which was then exported to the software NVivo (version 11). Nvivo was used to find common thematic nodes across all interviews. Threats to validity were minimised through triangulation of data collection methods (interviews, observations, internal and external documents) and verification of the initial thematic codes by participants, where they judged the accuracy of data collected, though not its conclusions (Tajeddini and Mueller, 2009).

Table 1: 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

The interviews were performed from December 2016 to January 2018; the duration on an average was fifteen to thirty minutes. Table 1 and Table 2 display the background of the professionals from the construction industry of the DR and UK who participated in the interviews. 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 1 to more than 30.

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Table 2: 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

To assist with the data analysis, a 5-step process based on 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 thematic 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 critical factors for a successful implementation of smart devices in the same sector. The findings are shown as a narrative which describes the perception of the interviewees.

Triangulation of data made possible through these means contributes to the reliability and validity of the study. The concept of triangulation is based on the assumption that any bias inherent in particular data sources, investigator or method used would be nullified when used in conjunction with other sources of data, investigators or methods (Saunders et al., 2019). In this study, relevant literature was used to confirm and support findings found from the data collected. In certain cases, data obtained from an organisation was triangulated through inquiring more than one employee.

The empirical findings from the semi-structured interviews led the way towards the developed framework. The developed framework was validated with five professionals of the UK and DR construction industry with more than 10 years of working experience. Two participants were selected from the United Kingdom and Three more from the Dominican Republic. In addition, 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.

According to Patton (2014), the use of a variety of methods helps ensure the credibility of the analysis and interpretation of the research. Saunders et al., (2019) refers credibility as a process undertaken to define how data and analysis have been executed. In this study, the researcher seeks the opinions of the participants on the findings and the validation of the framework which was developed based on the analysis of the data.

4 Findings

This section presents the findings obtained from the data collection discussed in the research methodology. 39 semi-structured interviews were performed to professionals of the Construction industry in the UK and DR. The findings are classified as Drivers, Challenges and CSFs for implementing smart devices in the construction industry. These findings emerged from a thematic analysis which produced common themes among respondents, a literature review was performed to extend the findings from the interviews. Interviewees were asked for the drivers, challenges and the critical factors for successfully implementing Smart devices in construction projects. Analysis of the qualitative data revealed the perception from the industry which was conceptualised and explained in sections 4.1, 4.2 and 4.3.

4.1 Drivers to implement smart devices in the construction sector

This section discusses the drivers to implement smart devices in companies within the construction sector. The themes obtained from the data analysis of the interviews were grouped into three major themes, namely, economic, managerial and corporate. 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 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.

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Table 3: 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

4.2 Challenges to implement smart devices in the construction sector

This section discusses the challenges to implement smart devices in construction companies. 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 groups namely, economic, cultural and technological. Table 4 presents the three key groups and their sub-themes which emerged from the qualitative data analysis of the collected data. These sub-themes represent the main challenges for the construction industries of the UK and the DR. In order of higher to lower responses all the sub-themes obtained from the interviews can be named as follows: Cost; Training and development; Hardware constraints; Organisational culture; Internet access; Technology awareness; Distraction of employees; Lack of leadership; Company size; Usability; and Project location.

Economic challenges had the highest rate of response, with 64% of the interviewee (23 out of 36) commenting about the cost and company size as challenges for adoption of smart devices. Cultural challenges were proposed by 58% of interviewees (21 out of 36) which proposed the following sub-themes: Organisational culture, training and development, lack of leadership, the distraction of employees and project location. Finally, Technological challenges were mentioned by 50% of interviewees (18 out of 36), suggesting, hardware constraints, internet access and usability as main issues to consider.

Table 4: 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**
Cost	56%	57%	54%	20	13	7
Company size	8%	9%	8%	3	2	1
Cultural challenges	58%	57%	62%	21	**13**	**8**
Organisational culture	19%	13%	31%	7	3	4
Training and development	19%	22%	15%	7	5	2
Lack of leadership	11%	9%	15%	4	2	2
Distraction of employees	6%	9%	0%	2	2	0
Project location	3%	4%	0%	1	1	0
Technological challenges	50%	52%	46%	18	**12**	**6**
Hardware constraints	19%	13%	31%	7	3	4
Internet access	14%	22%	0%	5	5	0
Usability	6%	4%	8%	2	1	1

4.3 CSFs to implement smart devices in the construction sector

Table 5 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. From the DR interviews, nineteen interviewees provided valid CSFs. Similarly, in the UK, eleven interviewees provided valid CSFs out of fourteen.

Table 5: 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

The findings presented in this section have been considered for the development of a strategic framework for implementing smart devices in the construction sector. 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.

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. In this study, 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.

5 Framework for implementing smart devices in the construction sector

Based on the findings presented in section 3 and a literature review performed to expand the ideas found through the data collection of this study, the following framework is developed. This framework proposes a strategic plan for construction companies to embed and adopt smart devices into their daily activities in the construction industry. The developed framework consists of two sub-frameworks, namely persuasion framework and implementation. Both sub-frameworks follow the innovation-decision paradigm explained by Rogers (1983) which conceptualises the innovation-decision process in five stages, as shown below (See Figure 1):

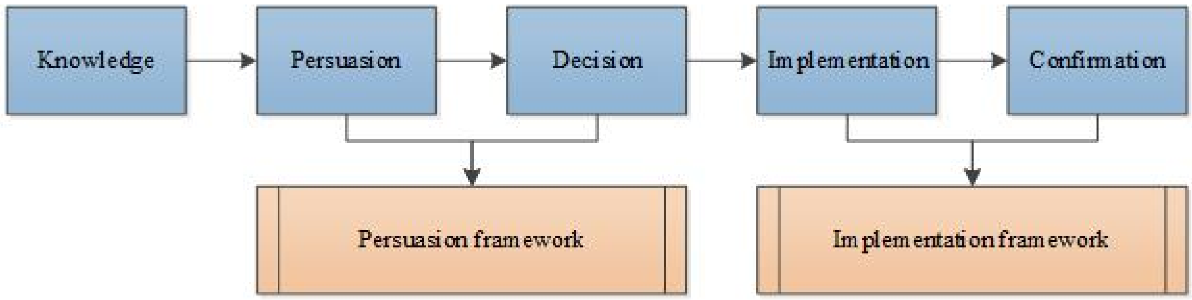

Figure 1: Rogers' Innovation-decision process and its relationship with the developed framework
Source: Rogers and Shoemaker (1983)

Rogers (1983) established that the innovation-decision process starts with when an individual gains awareness of an innovation 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 framework presents a list of critical actions to incentive technological innovation. These actions can persuade the decision makers and employees of construction companies about the positive benefits that come from the adoption of smart devices.

The decision stage occurs when an individual or organisation engages in activities that lead to a choice to implement or reject the innovation. As seen in Figure 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 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 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, therefore, companies which have already implemented smart devices can use the developed framework to revise and improve their IoT systems.

5.1 Persuasion framework

This framework presents a list of recommended actions to incentive a technological innovation in the construction industry which translates into the implementation of smart devices (see Figure 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

(TOE) framework which is described in Tornatzky, Fleischer and Chakrabarti's process of technological innovation (Tornatzky *et al.*, 1990). An analysis on this framework made by Baker (2012) was also considered in the building process of this framework.

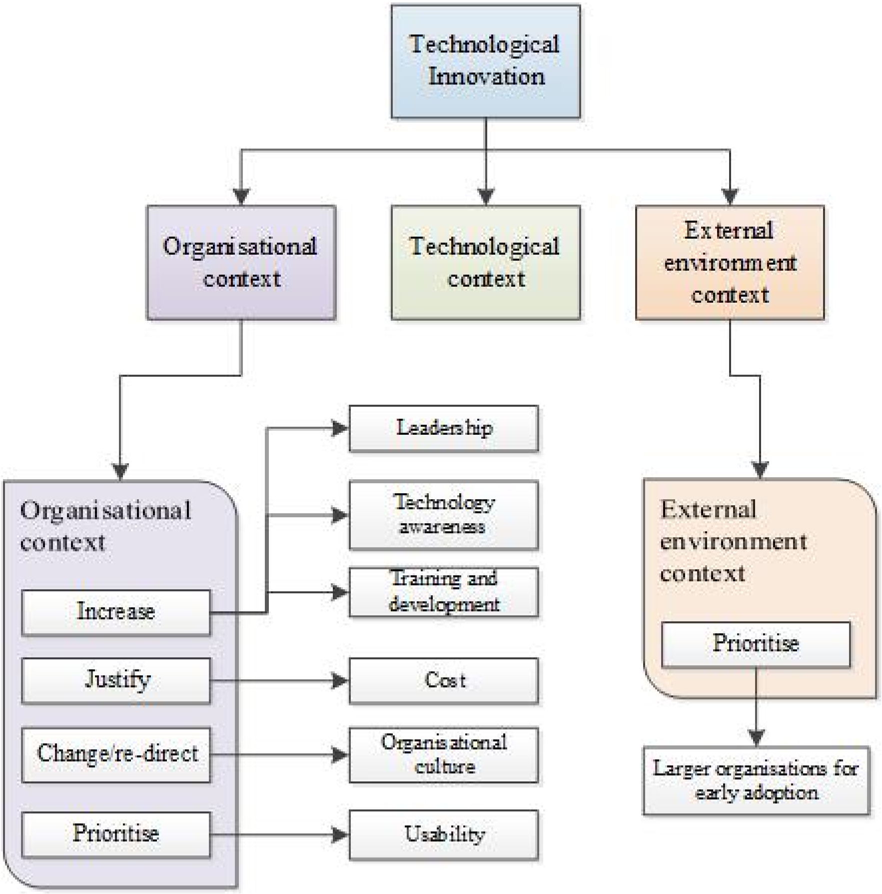

Figure 2: Persuasion-Decision framework - Critical actions to incentive technological innovation in the construction sector

To understand this framework, first construction companies 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; Baker, 2012). This framework can contribute to both the organisational context and external environment context within the technological innovation framework of construction companies.

The data collection performed in this investigation was made on an organisational level, the findings are mostly on the organisational context. Data analysis also revealed some recommendations for the external environment context. According to Baker (2012) 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 whereas the technological context addresses all the relevant technologies to the organisation, both technologies being used and available technologies in the marketplace to implement. Similarly, the external environment context describes the structure of the industry, the availability of technology service providers, and the regulatory environment.

5.1.1 Organisational context

As shown in Figure 2 within the organisational context there are various actions for construction firms to undertake. They are encouraged to improve 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.

Improving 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 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 if they do not show a profit in a cost-benefit analysis. Technologies like Daqri Helmet which in 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 deep under 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 to the changing 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. For instance, 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.

5.1.2 External environment context

The data analysis of the CSFs 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 (1983) corroborate this with the following set of generalisations about early and late knowers of innovations:

- 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 (1983).

5.1.3 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.

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5.2 Implementation framework

This sub-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 workflow of the framework is discussed in section 4.2.1. 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. 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 4.2.3. A feasibility analysis which considers important elements obtained from the data collection of this investigation and the literature is explained in section 4.2.4.

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 such as company IT requirements, stakeholders needs, existing IT infrastructure, recommended IoT system and key performance indicators.

5.2.1 Framework workflow

Figure 3 shows the workflow for implementing the most adequate IoT system in a construction company. As shown in Figure 3, 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.

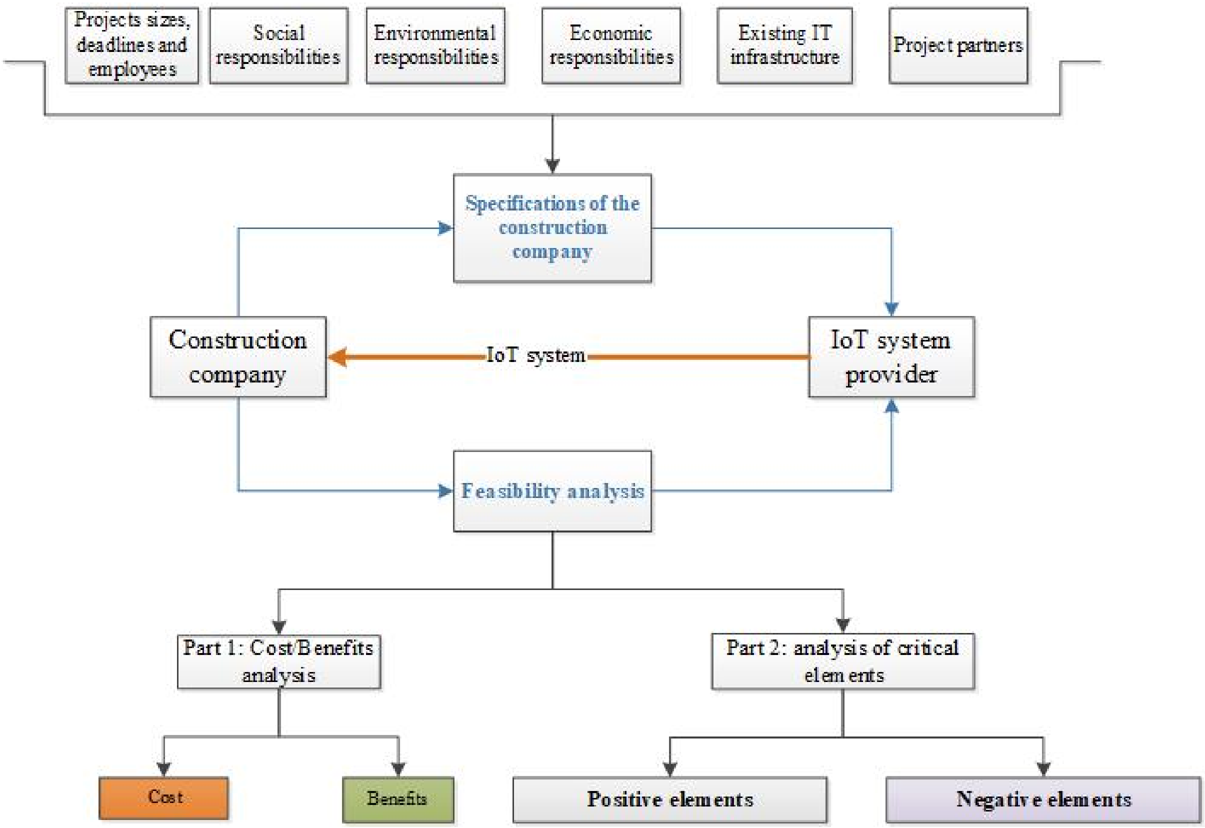

Figure 3: Workflow of implementation framework

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. The following section addresses the actors which participate in this sub-framework.

5.2.2 Actors

The actors who participate in this implementation sub-framework are construction company, IoT service provider and IoT system. Their role is as follows:

- 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.

The following section addresses the specifications that the construction company must provide to the IoT service provider.

5.2.3 Specifications of the construction company

The specifications of the construction company are a requirement for obtaining an IoT system. As shown in Figure 4 these specifications include information such as project specifications, social, economic and environmental responsibilities, existing IT infrastructure and project partners.

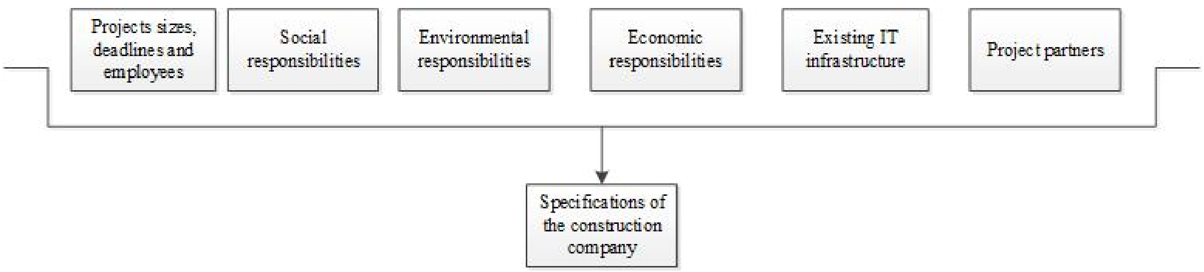

Figure 4: Specifications of the construction company

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, p. 46) who describes stakeholder as:

> *"any group or individual who can affect or is affected by the achievement of the organization's objectives"*

Once stakeholders are identified and mapped with their positive or negative impact in the project, there is a need to develop a deep understanding of their needs and how the organisation links with such needs. Also, it is necessary to list the technological resources for the stakeholders to be considered for the input of the framework.

5.2.4 Feasibility analysis

The feasibility analysis presents two processes for defining the most convenient implementation for the construction firm. Figure 5 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: 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.

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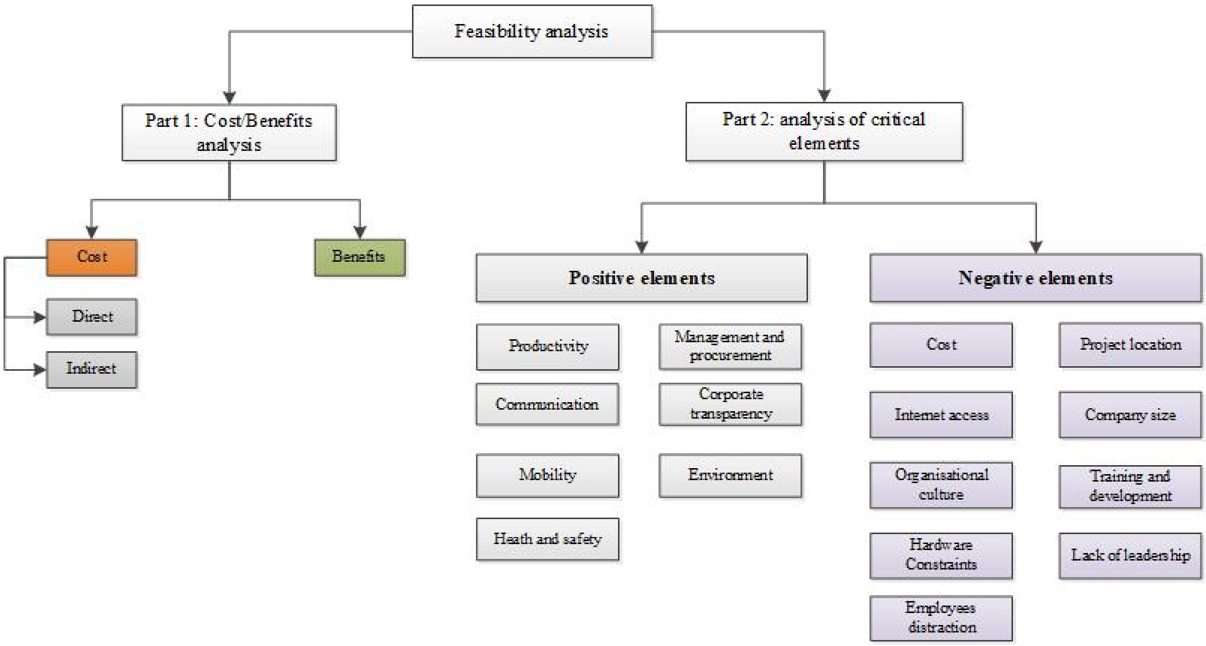

Figure 5: Feasibility analysis diagram

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 an 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 companies 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.

This stage of the framework's process section focuses on presenting the tools and recommendation for appraising 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.

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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 6 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)

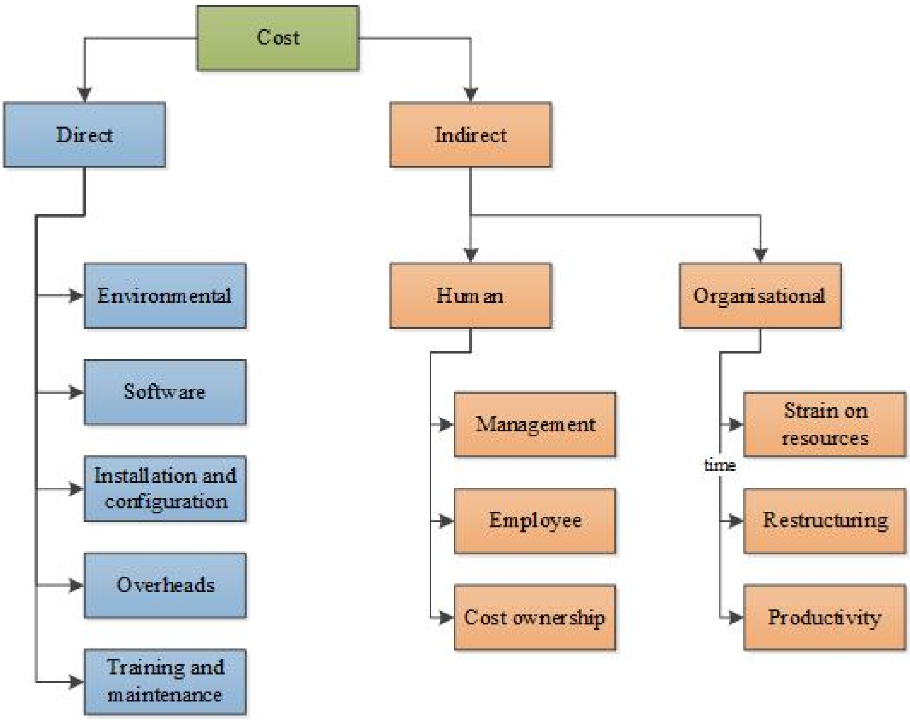

Figure 6: Scheme of types of cost in construction projects

Source: 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 companies. 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 that 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 6 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 6 aims at clarifying the differences between efficiency, performance and effectiveness benefits.

Table 6: 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.

Critical elements analysis

Section 3.1 presents 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 5. 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.

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.

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.

5.2.5 Key Performance Indicators

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, p. 80) 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 companies 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 7 presents a good guidance of objective and subjective measures to record KPIs offered by Chan and Chan (2004).

Construction companies 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 7: KPIs Objective and subjective measures
Source: 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

5.3 Validation of the framework

The developed framework was validated by five senior professionals of the construction industry. Two participants were selected from the UK and three were from the DR. 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 following questions were asked to the participants:

a) What is your opinion on the level of understanding of the proposed framework?
b) What is your opinion regarding the overall level of completeness of the proposed framework?
c) What is your opinion regarding the logic flow of the proposed framework?
d) Do you have further comments/suggestions regarding any areas that need to be improved/included/deleted within the proposed framework?
e) How would you describe the usefulness of this framework for companies in the construction industry?

Respectively, the feedback given by the participants of the validation process is explained below:

- *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.

- *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.

- *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.

- *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.

- *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.

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.

6 Conclusions and recommendations

This paper has discussed the development of a strategic framework to implementation of smart devices in the construction industry. The nature in the construction industry is 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 namely, persuasion-decision framework and 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.

Some of the key implications of the framework include the following:

- 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.

Implementing the framework proposed in this paper may have positive implications in construction companies which will use said framework as a guide to analyse their strengths and weaknesses to establish an action plan for integrating smart devices and the IoT in their operations. Several key aspects will be crucial in the definition of type and level of implementation of a construction company, such as social and technological context around the geographical location of the project; And organisational culture of the construction company implementing the framework.

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 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.

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 this paper can facilitate government/policy makers to develop guidelines or regulations for implementing smart devices. The feasibility analysis proposed in section 4 can be used to evaluate the scenarios when a construction organisation should or must implement smart devices.

This study considered the implementation of smart devices only 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)*. This is a key limitation of this study which could be addressed by future research. According to Yehevis *et al.* (2013) the lifecycle of construction projects contains three stages, namely, pre-construction, construction and demolition. Future research could evaluate the implementation of smart devices in others stages of construction such as for pre-construction and demolition stages.

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