

## Evaluating critical success factors for implementing smart devices in the construction industry: An empirical study in the Dominican Republic

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### 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 implementation of digital solutions during the execution of construction projects. This paper is aimed at assessing the critical factors for a successful implementation of smart devices in the construction industry.

**Design/methodology/approach:** An empirical study was performed in the Dominican Republic. This country, located at the heart of the Caribbean presents an economy that strongly relies on the construction industry. Following a systematic approach, a qualitative data collection and analysis was performed based on semi-structured interviews and content analysis to professionals of construction companies in the Dominican Republic, enquiring the concept of smart devices and critical success factors (CSFs) for implementing the devices in the industry.

**Findings:** The key success factors obtained from the contestants were Leadership, technology awareness, company size, usability of proposed solution, cost of implementation and interoperability.

**Originality/value:** This paper provides information to clients of the construction sector regarding the benefits of embedding smart devices into their business activities. Furthermore, this study provides a better understanding of the key factors to be considered by construction organisations when embedding smart devices into their projects. This study also provides recommendations for distinct stakeholders of the construction sector, such as policymakers, clients and technology consultants. Policymakers should especially consider factors such as technology awareness and leadership to develop the right policies for the integration of the IoT in construction projects. Technology consultants should be aware of the latest case studies of successful implementation of smart devices and IoT systems in the world in order to adapt and implement smart devices and IoT in their projects.

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

## **1 Introduction**

Smart devices are considered objects capable of communication and computation which range from simple sensor nodes to home appliances and smartphones; they are usually the objects present in the network of the Internet of Things (IoT) (Stojkoska and Trivodaliev, 2017) . They are the core devices in the integration of the paradigm of the IoT in current industries; playing a fundamental role in the implementation of digital solutions in the construction industry.

Traditional Internet consists of a global network that enables communications between computers. When connecting those computers, the main purpose of the Internet is connecting the users of those computers. The IoT, differently, is a network that connects things. Anything can be connected to this network (Miller, 2015). The paradigm of the IoT consists of a virtual interconnection of devices in the real world which provides valuable constant data gathering, data analysis, productivity tools, mobility, enhanced communication among stakeholders. There is a broad range of 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.

The 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 also the highest amount of external collaboration; this results in a high rate of subcontracting and interaction between workers. Additionally, the construction industry has the highest rate of mobile content access, resulting in stakeholders interacting and accessing content via mobile devices more than any other sector analysed by this study. This defragmented nature in the construction industry incentivises researchers and software developers to create innovative solutions based on mobile content access to increase productivity and fluid communication among stakeholders within the industry. The implementation of such innovative solutions calls for a systematic process which considers the critical factors for a successful implementation. Therefore, the purpose of this paper is to establish the critical factors for a successful implementation of smart devices in the Dominican Republic construction sector; this is a critical step towards the effective inclusion of smart devices and related technologies into the Architecture Engineering and Construction (AEC) sector of the country. Firstly, smart devices in the construction industry will be discussed followed by the research problem. This will be followed by research methodology, data analysis and discussion.

## **2 Smart device in the construction industry**

The concept of smart device defines how we consider the IoT in this study. Many authors use different terms to address smart devices such as “mobile devices”, “smart mobile devices” and “smart metering devices”. The key features that authors in the literature allocate to smart devices were grouped in the following terms: autonomy, connectivity, context-awareness and user-interaction. This paper considers smart devices as the objects present in the pervasive network of the IoT, following the theory of Stojkoska and Trivodaliev(2017). Therefore, the ability to interact with users is not necessarily required from smart devices, since as per Miller (2015) IoT

connects devices with devices, meaning that some devices within this network might never interact with users. Nevertheless, network connectivity is utmost required.

Network 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. For example, the high internet use is something common on smart devices; this infers the utilisation of smart devices for internet access which requires network connectivity (Harwood, *et al.*, 2014). More specifically, Sivaraman *et al.* (2018) states that IoT devices should possess network capabilities.

Context-awareness should also be considered as a key factor for a device to be considered smart. The main idea behind context-awareness is the ability of smart devices to perceive information from the environment through sensors (e.g.: camera, accelerometer, microphone, GPS). The information gathered through sensors can then be utilised to make autonomous decisions or to provide direct assistance to the user. One example is the utilisation of smart devices for photography or video recording (Godwin, *et al.*, 2013), On the other hand another example is the implementation of smart devices for human voice recognition (Husnjak, *et al.*, 2014).

Some smart devices are designed to interact with users, such as a smartphone, tablets or smart bracelet. Sivaraman *et al.* (2018) propose various scenarios where smart devices can be useful for users. In these scenarios smart devices interact on distinct levels with users by either collecting or providing data. One example is how smart devices allow 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 (Harwood, *et al.*, 2014). Despite there is a wide range of smart devices design for user interaction the paradigm of the IoT is based on the interconnection of devices or “things”, meaning that any device can be connected and just work as a hub for collecting or providing information to a bigger network (Miller, 2015). Consequently, smart devices do not necessary require a direct interaction with users.

Considering the existing literature, from an operational perspective a smart device can be considered as a context-aware electronic device, capable of performing autonomous computing and connecting to other devices wire or wirelessly for data exchange (Silverio-Fernández *et al.*, 2018). This definition suggests that any object can be transformed into a smart device by adding the right technology. Despite having a clear definition of smart device, there is a lack of research and conceptualisation within the construction industry of the Dominican Republic, which makes it difficult to establish a clear background on the concept of smart device and IoT within the industry.

Main technologies associated with smart devices in the construction industry are Cloud Computing (CC), Augmented Reality (AR), Building Information Modelling (BIM), and Geographical Information System (GIS). The main idea behind each one of these technologies is the following:

- CC makes applications and data available remotely, providing ubiquitous data access to its users. In the construction industry, it shows benefits such as cost reduction, mobility, flexibility and ease of maintenance (Silverio *et al.*, 2017). Based on the nature of the construction industry and the cloud computing model, Cheng and Kumar (2012) suggest four main benefits of CC for construction

collaboration and management, namely, cost, mobility, flexibility, and maintenance and updating. Whereas Brender and Markov (2013) establish the main topics of concern regarding the adoption of CC from a management point of view as: information security; privileged user access; regulatory compliance and data location; investigative support; availability and disaster recovery; and provider lock-in and long-term viability.

- 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, as explained by Chi, *et al.* (2013), AR creates an environment where computer-generated information is superimposed onto the user's view of a real-world scene.
- BIM integrates a 3D model for display and a data set of properties to maintain into an intelligent 3D model-based process that gives AEC professionals the information and tools to more efficiently plan, design, construct, and manage buildings and infrastructure. 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, *et al.*, 2014). Smart devices and the paradigm of the IoTs have been integrated with BIM to enhance efficiency and effectiveness of daily operations, decision making, collaboration, and supervision in construction projects (Li *et al.* 2018)
- 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. When GIS layout data is linked with three-dimensional (3D) site models, the whole material circulation path in the site can vividly simulated and two-dimensional GIS becomes three-dimensional (Irizarry *et al.*, 2013). The 3D GIS can use 3D database in distinct forms such as: imagery, digital elevation model for surface elevations, 3D model representing interior design of a building (Bansal and Pal, 2009). Additionally, GIS have been used together with BIM for management and analysis of key geospatial information for the transportation of heavy machinery (Tan *et al.*, 2018).

Smart devices and their related technologies provides enhanced communication and exchanged of information among their users. In the case of the construction sector, Liu *et al.* (2017) highlights the following perceived benefits of the use of smart devices in the New Zealand construction industry:

- More efficient management of documentation
- Improved efficiency and accuracy of site inspections and reporting
- Better client relationship management and satisfaction
- 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

- Better pricing and tracking of orders
- Real time tracking for prompt payments

These benefits have a positive relationship with the improvement of the productivity and profit in the New Zealand construction industry.

### **3 Research problem**

Going back two decades the construction industry compared badly against other industries in terms of capital cost, product quality, and client satisfaction (Egan, 1998;Latham, 1994). More recently, Farmer (2016) categorised the symptoms of failure and poor performance in the United Kingdom construction industry as low productivity, low predictability, structural fragmentation, leadership fragmentation, low economic margins, dysfunctional training, workforce size, lack of collaboration, lack of research and development, and poor industry image. Box (2014) reported that the construction industry has the highest mobility rate, highest collaboration rate between parties and highest decentralisation of information. Consequently, the AEC sector presents a prospective scenario for the implementation of smart devices and the paradigm of the IoT, which would attempt to enhance communication between stakeholders and boost efficiency and mobility in the AEC sector.

Despite providing a clear understanding about the issues in the construction sector, the literature does not provide research background for certain topics which might be too specific. In this case there is a lack of information regarding the key factors for successfully implementing smart devices in the AEC sector in the Dominican Republic. The literature was searched using the online services Google scholar and Science Direct. No relevant results were found for the Dominican Republic construction industry up to the year 2018.

The Dominican Republic 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 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 Dominican Republic (Central Bank of the Dominican Republic, 2016) on a national scale, the construction industry contributes to approximately 18% of the 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.

The Dominican Republic is intertwined with the Latin America economy, interacting with major players such as México and Brazil, which according to Hoffman *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 Dominican Republic surpasses the one of Costa Rica, which has a GDP of 57.43 billion US

dollars by 2017 (World Bank, 2018). Although, there are major players like Mexico and Brazil with a GDP of 1.047 and 1.796 Trillion US dollars respectively (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 Dominican Republic, this study provides an insight into the key factors to consider in data-scarce regions, which are prerequisites for developing strategies for embedding new technologies, such as smart devices, and the paradigm of the IoT within the construction industry.

## 4 Research methodology

This section describes the methodology implemented for collecting data in the Dominican Republic construction industry regarding the critical factors for a successful implementation of smart devices. Since there is no background theory in this field, a qualitative research approach was selected following the theory of Creswell and Poth (2017). This paper inherits and applies this theory of Streubert and Carpenter (2011) and Lincoln and Guba (1985), which states that transferability or possible generalisation of qualitative studies relies on potential users of the findings and instead of the researchers;

The questions necessary to fulfil this research were asked in semi-structured interviews. A set of fifteen semi-structured interviews were performed among ten companies from the construction sector, enquiring about: utilisation of smart devices in construction projects and critical factors for a successful implementation of smart devices. The sampling technique was critical case sampling; this is a type of purposive sampling technique that is particularly useful in exploratory research which allows to establish valid generalisations (Palinkas, *et al.*, 2015).

Determining the sample size of qualitative studies varies across literature; 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 sample size of this study was based on the principles for data saturation theory explained by Francis *et al.* (2010). First an initial sample size was determined; secondly, the researcher specified a stopping criterium, which consists of how many more interviews will be conducted, without new shared themes or ideas emerging. For this study the initial sample size was fifteen and the stopping criterium was three (same as Francis *et al.*, 2010), this means that in the last three interviews no new theme should arise.

The 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 1.

*Table 1: Classification of companies in the Dominican Republic based on number of employees, capital and revenue (Insert here)*

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: “please kindly tell me the most common utilisations given to ‘smart devices’ by you or others employees in the construction industry”. 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 (CSFs) for implementing 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. There were no ethical issues related to the interviews. The interviews were held in the city of Santo Domingo in the Dominican Republic. 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 2 displays the background of the professionals from the construction industry of the Dominican Republic who participated in the interviews, the company code, company size, nature and scope of operation, and the designation of the interviewees in each organisation.

*Table 2: Interviewees demographic information (Insert here)*

To assist with the data analysis, a 5-step process based on Creswell’s (2013) guide for qualitative data analysis was utilised. Overall these steps are transcription of audio interviews; preparation of transcripts; iterative review of transcripts; coding of transcripts; generations of themes. White and March’s (2006) approach was also a useful source of guidelines for performing qualitative content analysis and developing an inductive coding scheme. Firstly, the transcript from the audio interviews is developed. Secondly, the interviews are organised and prepared for data analysis, this task involved optically scanning the data and taking relevant notes from the transcripts. The third step consisted of an iterative review of all the transcripts, this step provided a general sense of the data and its overall meaning. Fourth is the coding step, the data was organised into segments of text before bringing full meaning to the information. Finally, the codes were used to generate themes which gives sense to the knowledge found in the coding stage.

The iterative review and coding of the transcripts yielded a deep understanding of the points made by the interviewees and resulted in the extraction of issues and generation of themes relating to the critical factors for a successful implementation of smart devices in the same sector. Threats to validity were minimised through triangulation of data collection methods (interviews, internal and external documents) and verification of the initial thematic codes by participants, where they judged the accuracy of data collected. Out of fifteen interviewees, ten provided valid CSFs. This is due to their surrounding context and experience. Some companies appeared not to have much contact with the smart devices and technology. This was not because of the company

size but because of factors such as lack of leadership. The findings are shown as a narrative which describes the perception of the interviewed construction companies.

## 5 CSFs for a successful implementation of smart devices in construction projects

This section discusses the six 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 AEC sector. Interviewees were asked for the critical factors for successfully implementing smart devices in construction projects. Analysis of the qualitative data revealed the perception from the industry which was divided into the following categories: leadership, technology awareness, company size, usability of proposed solution, cost of implementation, and interoperability. Table 3 shows the interviewees responses obtained via semi-structured interviews, it presents the response rate of the CSFs based on the comments of ten interviewees. This table provides an idea of the relevance of each CSF. Following these results, the CSFs are explained by order of relevance, being leadership the most mention CSF (four interviewees) and interoperability, cost and usability the least relevant (one interviewee each).

*Table 3: Response CSFs obtained from interviewees in the Dominican Republic*

### 5.1 Leadership

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.” (Respondent 09 - Company DR-05 – Resident engineer)*

Also:



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*“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.” (Respondent 13 - Company DR-10 – Project manager)*

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.” (Respondent 12 - Company DR-10 – Project designer)*

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.” (Respondent 04 - Company DR-04 – Director)*

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.” (Respondent 13 -Company DR-10 – Project manager)*

In general, 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 04 and 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.

## 5.2 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 states 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 05 – Company DR-05 – BIM manager)*

This interviewee considers there are two groups of professionals within the construction industry. First a group of young professionals 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 11 – Company DR-09 – Drawing coordinator)*

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 12 - Company DR-10 – Project designer)*

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 15 - Company DR-10 – Project manager)*

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 if we intend to increase the awareness of technology within an organisation, we need to think of changing its culture.

### 5.3 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.

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 14 – Company DR-10 – Project manager)

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 01 – Company DR-01 – Resident engineer)*

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 employees number, number of project 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.

#### 5.4 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 06 - Company DR-06 – Project manager)*

Also:

*“... ease of use and fulfilling general requirements such as the network, having an existing infrastructure for them (Smart devices) to work.” (Respondent 12 – Company DR-10 – Project designer)*

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.

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.

### 5.5 *Cost of implementation*

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 01 - Company DR-01 – Resident engineer)"*

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.

### 5.6 *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 06 - Company DR-06 – Project manager)*

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, 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.

## **6 Conclusions and recommendations**

The construction industry is one of the main components of the worldwide economy. Thus the embedding of new technologies such as the IoT promises a more efficient sector with more centralised information exchange between stakeholders. The literature showed various benefits in the implementation of smart devices and the paradigm of the IoT in construction projects such as a more efficient management of the workforce and reduced risks and liability on the job site (Liu *et al.*, 2017).

This study is based in the consultation to professionals of the construction industry in the form of semi-structured interviews, which identified the key factors for a successful implementation of smart devices in the construction industry of the Dominican Republic. It also provides a starting point for raising awareness to facilitate and implement smart devices in construction projects. In the absence of empirical literature on implementation of the paradigm of the IoTs in the construction sector in general, this paper presents a useful contribution to the growing body of knowledge.

The paper has identified six CSFs that can contribute to the adoption and implementation of smart devices in the AEC sector. The body of knowledge of the AEC sector can benefit from the CSFs and their order of relevance for the industry. The CSFs are:

- Leadership
- Technology awareness
- Company size
- Usability
- Cost of implementation
- Interoperability

This study shows both benefits and CSFs for implementing smart devices in the construction sector. Various benefits refer to a more efficient management of timesheets, employees, customers and documentations; this produces a better time and cost of implementation which relates to the CSFs of cost of implementation. Exposing the benefits behind the implementation of smart devices will translate in a better decision making among the main industry decision makers. Nevertheless, the benefits should be accompanied by barriers of implementation to enable decision makers to evaluate pros and cons. Technology awareness plays a fundamental role to understanding case studies which show the benefits behind the implementation of smart devices, as well as during the selection process of the devices to be implemented for a specific company or project.

The key factors obtained in this study relate differently with 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.

It is necessary 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.

The construction industry in the Dominican Republic relies on the private sector (private companies and consultants) and public sector (government). All these stakeholders need to recognise the benefits of implementing something new, before this implementation can take place. In the IoT, the data can be mined and processed in order to provide continued assistance to users of smart devices in the construction industry. To obtain richer data it is required the integration of private and public sector.

Construction companies outside the Dominican Republic should also consider leadership as one of the main CSFs for implementing smart devices in their projects. One example is the United Kingdom, where according to Farmer (2016), there is a highly fragmented nature of leadership and decision making in the UK construction industry which translate 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.

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 paper 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.

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*Table 2: 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

*Table 2: Interviewees demographic information*

No.	Contractor	Profession	Position	Company size	Sector	Experience in construction (years)
1	DR-01	Civil engineer	Resident engineer	Small	Private	> 3
2	DR-02	Civil engineer	Resident engineer	Large	Public	> 30
3	DR-03	Civil engineer	Director	Micro	Private	> 2
4	DR-04	Civil engineer	Director	Micro	Private	> 12
5	DR-05	Architect	BIM manager	Small	Private	> 4
6	DR-05	Civil engineer	Project manager	Medium	Private	> 5
7	DR-05	Civil engineer	Project manager	Large	Public	> 6
8	DR-06	Civil engineer	Project manager	Micro	Private	> 4
9	DR-07	Civil engineer	Resident engineer	Small	Private	> 9
10	DR-08	Civil engineer	Resident engineer	Small	Private	> 6
11	DR-09	Architect	Drawings coordinator	Large	Public	> 4
12	DR-10	Architect	Project designer	Medium	Private	> 4
13	DR-10	Civil engineer	Project manager	Medium	Private	> 5
14	DR-10	Architect	Project manager	Medium	Private	> 5
15	DR-10	Architect	Project manager	Medium	Private	> 10

*Table 3: Response rate of CSFs obtained from interviewees in the Dominican Republic*

CSF	Response rate (% from 10 interviewees)
Leadership	40%
Technology awareness	40%
Company size	20%
Cost of implementation	10%
Usability	10%
Interoperability	10%