RFID use in residential/ commercial construction industry

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Abstract

Purpose – In the past decade, radio frequency identification devices (RFIDs) have attracted the attention of the construction industry, having been proven to be an effective technology for addressing operational challenges in other industries such as health-care, retail and manufacturing. Despite the benefits, the use of RFID in construction industry is limited even in the face of inefficiencies that exist and that the need for improvement is yet to drive the widespread adoption in the residential/commercial construction industry. The purpose of this study is to investigate key drivers and critical success factors for RFID adoption.

Design/methodology/approach – The study included extensive and systematic literature review, interviews and questionnaire survey.

Findings – The study revealed that the most important key driver for RFID adoption is productivity improvement, while the most important critical success factors include management support and commitment, having clear RFID strategy, needs and benefits, having strong motivation for improvement, providing adequate funding and proper planning.

Practical implications – This study provides an exploratory framework that can be used by construction company executives and managers to provide justification for deciding to implement RFID on their projects and to enhance success rates of implementation.

Originality/value – This study contributes to the knowledge on RFID use in residential/commercial construction industry and provides a basis for further investigation by construction management researchers on the emerging issues regarding RFID use in the construction industry.

Keywords Critical success factors, RFID, Construction, Key drivers, Residential/commercial

Paper type Technical paper

Introduction

Modern technological advancement presents many opportunities for industries and companies to improve their work processes and achieve project goals. Different technologies have emerged to assist in real-time information exchange and address operational challenges not only in construction but also in other sectors. Radio frequency identification device (RFID) is one of such technologies which has been developed and applied extensively in industries such as manufacturing, retailing and health-care.

RFID can be described as a technology that consists of special tags or transponders, a reader or transceiver and an antenna that allows the reader to communicate with the transponders. The technology is based on exchange of information by means of electromagnetic signals with the ability to identify and track objects. RFID technology is more advanced than the previously widely used bar code technology because of its capability to store and process data (Koh *et al.*, 2006). Although the experimentation of RFID application in the construction field begun in the 1990s (Valero *et al.*, 2016), the technology

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has not been widely adopted. However, in recent years, there has been an increased interest in RFID from the construction industry with a number of companies testing and applying the technology to improve their construction processes (Atlas RFID, 2017). Additionally, IT vendors and developers are providing pilot solutions to specific construction problems for interested companies. The benefits reported from the limited use of RFID in construction make a compelling case for adopting and utilizing the technology for construction processes (CoreRFID, 2009).

RFID has been substantially developed and applied in other industries and proven to be effective in tracking different company assets, consequently helping address operational challenges (Lee and Shim, 2017). Many of these benefits achieved in other industries should also be achievable in construction and maintenance of buildings because of similarities in operational workflows and asset and resource management. Some of the most important benefits are direct and automated surveillance maintenance programs, inventory control, control of right equipment at right place and reduction of data entry errors both during production and maintenance (Chae and Yoshida, 2010). Importantly, the adoption and utilization of RFID will provide automation in the construction workflows significantly changing how construction companies conduct business.

Valero *et al.* (2016) reviewed the state-of-the-art use of RFID in the construction industry and concluded that several limitations and gaps that still exist in the construction industry limit contractors from choosing and adopting newer available technologies into their business. Consequently, the slow uptake, use and adoption of RFID technology in construction is of particular concern to both researchers and construction industry practitioners. As is the case in any emerging technology, construction companies tend to be slower adopters, and this, among other factors, has been attributed to resistance in the management process. With every technology, it is imperative that stakeholders are not only convinced of the potential benefits but also the practical application success and factors that increase this success. Critical implementation factors that represent major influences of RFID adoption by construction companies must therefore be investigated and disseminated to enhance the adoption and success rates.

Given the current rate of adoption and current state of RFID usage in construction, it is imperative to review the key drivers and best practices, which construction companies can focus on to create innovative-adoption framework. Also, to realize the full benefits of RFID adoption, there is the need to identify and analyze the critical success factors (CSFs) of RFID adoption. Many studies have been conducted on CSFs in other industries such as retailing, manufacturing and health-care (Attaran, 2012; Hung *et al.*, 2010; Koh *et al.*, 2006; Ting *et al.*, 2009). However, there is a lack of RFID studies to explore key drivers and CSFs in the residential/commercial building construction industry. This study intends to fill this gap by examining the factors that improve the successful adoption and implementation of the technology.

Aim and objectives

More industries are realizing the benefits of using RFID in their business, whereas in the construction industry, the use of these technologies is limited even in the face of inefficiencies that exist in material management, labor management, equipment tracking, etc. The need for improvement and benefits of RFID is yet to drive its widespread adoption in the construction industry. Therefore, this study aims at investigating the key drivers and success factors of the adoption of RFID in residential and commercial construction. The following objectives were formulated to achieve the stated aim as follows:

- to identify and categorize the key drivers and success factors of RFID adoption and implementation through extensive literature review;
- to solicit the views of building construction personnel with experience in using RFID on projects on the importance of the identified success factors through a questionnaire survey; and
- to rank the factors based on their criticality to the success of RFID implementation using statistical technique and provide a framework for RFID adoption in the building construction industry

Literature review

There has been a rapid growth in the use of RFID technology over the past decades in several industries such as retail, health-care, security, aviation, facility management, logistics and manufacturing. The transformation to automated production and handling in these industries in the past has resulted in the development of effective practices for considering automation during product development, design, security and supply chain management (Era Build, 2006). An understanding of the practices of other industries could effectively enhance consideration of automated technologies in the construction industry.

The use of RFID technology is not new to the construction industry, although it is not being widely applied on a large scale. For example, according to Schneider (2003), the transportation industry in USA used RFID in equipment identification, toll fare collection, fleet management, railcar management and fuel dispensing (Schneider, 2003). However, there is a plethora of research studies conducted on RFID in construction in the past decade indicating an advancement of theoretical research beyond the actual practical implementation. This reveals that interaction between academia and industry is not fully utilized as a driving force of the industry adoption (Li and Becerik-Gerber, 2011).

The market for RFID technology is rapidly growing with a current estimated value over $10bn annually. This is a far cry from 2004, when the RFID market was just $400m. By 2020, the RFID segment's value is expected to climb to $13.2bn (Retail Info System, 2016). This emphasizes the importance of RFID technology and the benefits being accrued from its application, leading to continuous adoption and usage expansion. RFID and automated technologies are changing operational practices for the better, and construction companies can improve their processes by using such technologies.

Radio frequency identification device technology definition

RFID device is a universal term given to any technology that uses radio waves to identify and track items. It is defined as a technology that aids in information exchange using electromagnetic signals Lu *et al.* (2010). According to Finkenzeller (2010), this technology does not require that the reader and the receiver be on sight with each other to communicate through radio waves (Finkenzeller, 2010).

The primary components of an RFID system are shown in Figure 1. This system requires tags or transponders, readers and an antenna for it to function. The small chips referred to as tags have the capability of sending data signals through radio waves. The tags are attached to physical items or materials to be identified. The data signals are received by an "interrogator" or "reader" for interpretation of the tag's data (Haddud, 2011). The readers can be stationary or mobile (HHC). An antenna establishes the communication between the transponder or tag and the reader. Subsequently, the reader communicates with a computer by means of an application, which manages the data received from the transponders.

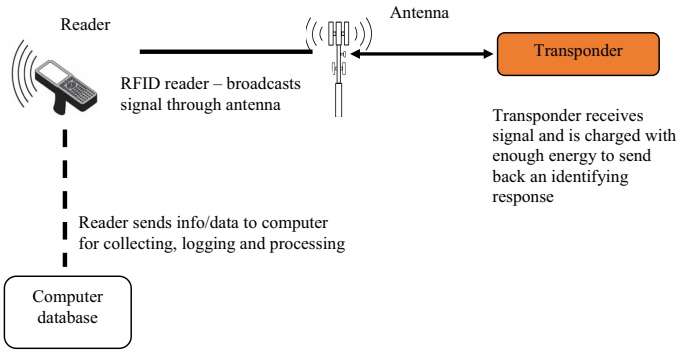

Figure 1.
Components of the RFID system

Exploratory analysis of radio frequency identification device application in construction. Several researchers have investigated the application of RFID in construction in different areas. Wang *et al.* (2007) argued that to obtain real-time information and information sharing among the involved participants of the construction supply chain, some research efforts have to be made focusing on RFID technology. Furthermore, a number of authors have looked at the automation of material management and specifically on the application of RFID based techniques (Caron *et al.*, 2007; Grau *et al.*, 2009; Jang and Skibniewski, 2008; Wan and Kumaraswamy, 2009). Other authors who have contributed to this area of research include Song *et al.* (2006), who looked at the application of RFID in tracking, delivery and locating fabricated pipes, Torrent and Caldas (2009), who focused on structural steel members, Tzeng *et al.* (2008), who investigated its application in interior decorating materials, Ergen and Akinci (2007), who reported on engineered to order components, and Wang (2008), who documented the application of RFID in quality management.

Other studies have developed management systems using RFID. Yin *et al.* (2009) developed a precast production management system using RFID technology to automate the collection and transmission of multi-faceted information such as the production quantity, the materials quantity, quality control inspection and inventory and transportation management information. Chin *et al.* (2008) developed an information system to manage the logistics and progress control of structural steel works under the integrated environment of RFID and four-dimensional computer-aided design (4D CAD). The system was validated and verified through real-world applications in two high-rise building construction projects. Likewise, Dziadak *et al.* (2009) developed a model for the three-dimensional (3D) location of buried utilities based on RFID technology. This provided the ability to physically determine on site the location of underground utilities which is critical to reduce risk and consequence during excavation.

The research studies are not limited to material management. Some studies have also focused on equipment and tool management. Goodrum *et al.* (2006), in an effort to improve the efficiency of tracking tools and improve their availability, developed a tool tracking and inventory system which is also capable of storing operation and maintenance (O&M) data using RFID. Chae and Yoshida (2010) developed a system using RFID to estimate working areas and equipment tracking to prevent collision accidents with heavy equipment such as hydraulic excavators and cranes. It is important to state that all the above research studies have reported significant benefits in the application of RFID in improving the efficiency of workflow and resource management.

Despite an upward trend in the amount of research being conducted on RFID application in construction, not many applications of RFID have been seen in real-life construction practices. However, as stated earlier, RFID has been extensively applied in other industries such as manufacturing, retail and distribution. It is important to state that the construction industry has characteristics that separately are shared by other industries but in combination appear in construction alone (Hillebrandt, 1984). The areas seeing the applications of RFID in other industries can also be seen in construction Lu *et al.* (2010).

Several reasons have been attributed to the relatively slow adoption rate of RFID in construction as compared to other industries. According to Lu *et al.* (2010), some of the possible reasons for the slow use include challenges in technology, financial, health and ethical issues. This offers a motivation for the authors to investigate the key drivers, as well as CSFs, of RFID use. Key drivers in this sense are the underlying factors that influence the adoption of a technology (RFID). On the other hand, CSFs are those elements necessary to enable a positive outcome on the use of RFID in residential/commercial construction.

Key drivers of radio frequency identification device

The key drivers are the reasons why companies implement RFID. In the process of identifying the key drivers of RFID use in an organization, it is equally important to understand the motivation behind the adoption. This might have an effect on how the technology is utilized by the implementing organization (Sharma and Citurs, 2005). For example, when an organization uses RFID technology to conform to the institution's environmental pressures, it might be doing so to satisfy its legitimacy needs.

Construction sites are challenging environments to manage, and there are many problems encountered in different elements when trying to meet project objectives. Today's construction companies face a unique set of both managerial and operational challenges. Acquiring material quickly, managing on-site labor, operating fleets of vehicles and ensuring that expensive assets are secure and being utilized to their full potential are daily activities on a job site. Furthermore, the ever-changing environment of construction sites introduces issues such as theft, misplacement, safety issues and unauthorized use of equipment requiring a more efficient tracking and control system like RFID technology.

To this end, several key drivers can influence the adoption of RFID in construction. These include the need to improve tracking of labor, material and equipment, reducing waste and optimizing resource usage, reducing operation time and cost, improving productivity and safety of workers, reducing inventory and theft on site and improving customer satisfaction. According to Burger (2018), 53 per cent of surveyed construction companies reported decreasing or halted productivity over the past five years. This is attributed, in addition to other factors, to difficulty in efficiently managing and supervising personnel and tracking tools (Burger, 2018). Automated systems can help ensure that tools and equipment for a project are going to the right place, maximizing employee efficiency. Having the proper tools and equipment at the right place and the right time will drastically reduce project interruptions and increase productivity. These factors unequivocally decrease cost. According to the National Insurance Crime Bureau, the construction industry suffers $1bn in losses every year due to theft of equipment and tools and a lot of that stems from mismanagement of inventory (Hedmond, 2015). Costs incurred from this type of loss range beyond replacement fees to impact on productivity, delays and even injury. Tracking systems provide better accountability and reduce theft in the sense that if a tool or piece of equipment goes missing, managers can pinpoint the last employee to handle the item using the automated tracking systems.

In the course of building construction, thousands of materials and crew of workers equipped with tools and vehicles are permanently changing their position in the workplace. The efficient control of these movements ultimately helps improve the productivity in building construction and increase the safety of workers. This reduces operation time and cost and consequently helps the profitability of the company. Construction companies manually supervise, track and record these construction activities, which is time-consuming and expensive. Manual data collection is not only tedious and an inefficient process involving printing and delivering paperwork but also is slow and often inaccurate (Burger, 2018). RFID has been proven to improve the quality of data within organizations by replacing manual data collection methods with automated ones (Valero *et al.*, 2016). It can help make information about assets or resources more visible by enabling the collection and consolidation of information for reporting and improving accountability through clear identification of what and when functions were performed by employees.

RFID allows information to be read or written, without contact, on tags that can be fixed to any of the tools or materials used in construction. The RFID automated system combines a company's assets and material data into one centralized and easily accessible database (Burger, 2018). These systems can be applied to the warehouse inventory and to the field personnel to streamline the accounting and tracking for all the company's resources. A report by the Construction Industry Research Program (2007) identified RFID as a potentially key technology for supporting the construction industry. The report concluded that RFID "offers construction new opportunities to improve the maintenance of assets and manufacturers to develop new products and services". The program highlighted areas of potential cash savings and efficiency improvements through increases in productivity, data capture, job tracking, quality control, stock management and improving customer information and satisfaction (Hodge, 2007).

Studies conducted on RFID application in construction have also highlighted the benefits and importance of RFID technology. According to Wing (2006), management of the complicated logistics involved in building is one of the main reasons companies are turning to RFID, as it assists them to track people, machines and materials. RFID can increase the service and performance of the construction industry with applications in materials management, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations and construction safety (Schneider, 2003). The confirmation that an employee is on site offers huge benefits to a contractor, particularly when they employ large teams of people across several different sites and geographies. RFID also helps with health and safety compliance, and it plays a pivotal role in improving accuracy and productivity in all phases of the construction process including planning, building, maintenance and operating Lu *et al.* (2010).

Critical success factors of radio frequency identification device

According to Bullen (1995), the concept of CSFs was first introduced in 1979 and has been used by organizations for strategic planning purposes. CSFs help managers to determine which elements must go right to achieve the goals and objectives of the process or tool to be used. The CSFs method has three steps:

(1) listing the goals and objectives;

(2) Identifying the CSFs necessary to achieve the goals and objectives; and

(3) suggesting ways in which the CSFs are to be measured.

CSFs of RFID adoption are a set of factors that an organization can use as guidelines to successfully implement RFIDs. An organization intending to be success at implementing RFID and realize its full benefits must therefore identify and analyze these CSFs (Vanany and Shaharoun, 2008). Furthermore, it is important that the implementing organization be interested in the technology use and identify which are the critical areas that they are interested in using RFID. This can help the organization avoid poor management of the technology and thus failing short of realizing the benefits they offer.

In its application, RFID needs careful planning aligned with business to ensure its successful implementation (Lim and Koh, 2009). While substantive RFID research has taken place in other industries, RFID research in the construction industry is in its infancy. It is timely, therefore, that this research focuses on the CSFs of using RFID in residential/commercial construction borrowing from the success in other industries.

A number of researchers have looked at CSFs of RFID adoption in different industries. However, there is lack of RFID studies in the literature that examine drivers and CSFs of RFID adoption in residential and commercial construction. Therefore, this study relies on its exploration, drivers and CSFs currently identified in the literature from different industries, e.g. in health-care, (Janz, Pitts, and Otondo, 2005; Yue *et al.*, 2008; Vanany and Shaharoun, 2008; Ting, Kwok, Tsang, and Lee, 2009), manufacturing (Fish and Forrest, 2006; Attaran, 2007; Ngai *et al.*, 2012) and retail (Reyes and Jaska, 2005; Shi and Yan, 2016), as shown in Table I. The critical factors can broadly be divided into three categories:

(1) *Organizational*: These are the factors that must be considered for a harmonious inter-relation between the different stakeholders and workers within the system. These factors are aimed at providing system vendors, managers and RFID users with a proper environment for the system to work successfully. These include strong internal and external motivation for improvement, clear RFID strategy, needs and benefits, measurable business benefits (return on investment, ROI) and continually improving procedures.

(2) *Managerial*: These factors will help in setting up the organization and directing, motivating the employees, coordinating and controlling various functions of the enterprise. It will also include such factors as trainings, funding, coordination and directing procedures. Examples include management support and commitment, proper planning and project management (teamwork).

(3) *Technical*: These factors deal with the operational issues of RFIDs. They will include factors such as the choice of software data storage and security, reusable tags and database specification.

Methodology

A mixed-method approach consisting of literature review and questionnaire survey was used in this study to investigate the key drivers and CSFs of RFID adoption and implementation in the residential/commercial building construction industry.

Literature review and expert interviews

The authors conducted an extensive literature review with the aim of identifying the key drivers and CSF of RFID adoption and implementation found in the mainstream publications. The literature review included a search of key words in the leading research databases such as Google Scholar, Business Complete, ProQuest and ASCE library to collect published journal articles on RFID in different industries. The search was more general and

Table I. Key drivers and CSFs established in literature

Industry	Author(s)	CSFs	Key drivers
Healthcare	Janz *et al.* (2005)	The acceptability of the technology by the medical and IT staffs during the data collection period.	
		The effectiveness of procedures for collecting, preparing, and analyzing RFID generated data.	
		The identification of opportunities for future projects	
	Yue *et al.* (2008)	The choice of hardware and software	
		How RFID integrates with other system	
		Data storage capacity, accuracy, data filtering, integration, data sharing security, data transmission speed and data security	
	Vanany and Shaharoun (2008)	Creating strong internal and external motivation for improvement	Anti–theft/anti-counterfeit
		Developing a clear RFID strategy	Improving patient safety
		Partnership with competent RFID providers	Refining business process
		Top management support and commitment from leadership	Improving patient satisfaction
		Facilitating equipment vendor's investment	Improving staff morale
		Integrating RFID into an existing IT architecture	Reducing cost and time
		Proper staff training	Improving productivity
		Starting with small RFID project	Reducing inventory
		Utilizing a cross-sectional team	
		Avoiding major process changes/limit process changes	
		Coordinating among department	
		Continually improving procedures	
		Integrating the data collected	
		Lack of comprehensive facts and data	
		Using cost-effectiveness reusable tags	
	Ting *et al.* (2011)	Good project management	
		Clear vision	
		Top management support	
		Effective communication	
		Appropriate vendor selection	
		Effective testing	
		Change management	
		Introduction of organizational learning	
		Well-structured system architecture	

(*continued*)

Table I.

Industry	Author(s)	CSFs	Key drivers
Manufacturing	Fish and Forrest (2006)	Vendor selection Organizational motivation Cos/benefits evaluation Top management support User involvement Staff competence and training Policy, structure and operation process compatibility	Reducing machine downtime Reduce non-working time Reduce defect rate Increase efficiency On time delivery Increase coordination among departments Improve staff motivation
	Attaran (2007)	Clearly defined business needs/benefits Top management involvement Proper planning/scoping Measurable business benefits (ROI) Adequate funding Partnership with competent technology providers Integrating RFID into a company's existing IT architecture Determining which practices should be incorporated into their RFID systems Project management (teamwork) Proper staff training and participation	Visibility along the supply chain Information retrieval Accurate asset tracking Better-quality information Better decisions Improved productivity Reduced operating costs Improved business process Improved quality and reliability Improved competitive position
	Ngai *et al.* (2012)	Vendor selection, Organizational motivation Cost/benefit evaluation Top management support User involvement The extent of progress supervision Staff competence and training, and policy Structure and operating process compatibility	

(*continued*)

Table I.

Industry	Author(s)	CSFs	Key drivers
Retail	Reyes and Jaska (2005)	Understand what RFID can and cannot do Analysis of present system Build a ROI business case Testing the proposed RFID system Monitoring Continuous improvement Complexity Organizational compatibility Top management support Entry timing Organizational readiness External factors Technology competence Size Consumer readiness Partner readiness	Perceived benefits Competitive pressure Firm performance is enabled or constrained by industry structure Presence of resources that meet certain conditions, such as value, rarity, imperfect imitability and lack of substitutability
	Shi and Yan (2016)	Technological complexity Technological compatibility Perceived effectiveness Cost Organizational size Upper management support Trust between enterprises Technical knowledge Employee resistance Competitive pressure Uncertainty	

broader because of the limited application of RFID in construction industry and building construction in particular.

The search resulted in a total of 311 papers, which were further evaluated for relevancy and to avoid double counting. Evaluation included reviewing to ascertain whether the papers were within the scope of this research. The evaluation resulted in cutting down the number to 156 studies. Further review and evaluation narrowing down to specific key drivers and CSFs resulted in 85 empirical studies that were used for this research. Table II shows the yearly trends of the articles that were reviewed and their sources.

The review revealed an increasing trend in the number of published papers on the subject matter over the years. This shows that there is an interest both from researchers and practitioners on the use of RFID. However, it was noted from literature that research on RFID adoption in construction and building construction in particular is limited. This aroused the need to adopt all the key drivers and CSFs of RFID use in all industries and investigate further those that are applicable in residential/commercial building construction. Through the review, 29 success factors and 20 key drivers of RFID were initially identified and formed the basis for further study.

Going forward, the authors considered it worthwhile to conduct interviews with professionals who are knowledgeable and/or experienced with RFID. The aim of the interviews was to gather their experiences and compare with the information from the literature to ensure all relevant factors have been covered. The interviews were also to help narrow down the factors to those relevant to the building construction industry. Two project managers from two different General Contracting companies in the building industry were approached for the interview. Both interviewees have experience with RFID and agreed to participate in the interview. The interviews were conducted over the phone. The process of conducting the literature review, developing and conducting the interviews took about six weeks. After the literature review was concluded and the collection of expert feedback was completed, a qualitative survey to garner data about industry professionals' perceptions was needed. Results of the literature review and interviews were used to develop questions for the survey contained in this paper.

Publication source	Five-year publication period			
	1998-2002	2003-2007	2008-2012	2013-2017
Journal of Retailing	2	3	2	3
Construction Management and Economics	0	1	2	4
Journal of Shopping Center Research	0	5	4	6
Supply Chain Management: An International Journal	0	3	4	7
Journal of Supply Chain and Operations Management	2	2	4	5
Production and Operations Management	0	1	0	2
Books	0	1	1	1
Business Process Management Journal	0	0	1	2
Journal Information Technology and People	0	0	0	3
Others*	2	1	3	7
Total (n = 85)	6	16	24	39

Notes: *Others include journals with >3 papers reviewed: *Construction Management and Economics, Journal of Computing in Civil Engineering, International Journal of Architecture, Engineering and Construction, Journal of Purchasing and Supply Management* and *International Journal of Project Management*

Table II. Yearly trends in drivers and CSFs of RFID research published in mainstream journals

Survey

In general, surveys provide a numeric description of a phenomenon, trend or opinion of a population by systematically studying a sample of that population that can be generalized. The development of the questionnaire for the survey in this research resulted from narrowing down the key drivers and CSFs following the literature review and interviews with industry practitioners. The survey was pretested with one researcher who is an expert in the area of RFID and one industry practitioner.

The intent of the survey was to attain information from professionals that have had experience with RFID in the residential/commercial building construction industry. The questionnaire developed contained four sections: Section A: respondent's experience; Section B: respondent's profile; Section C: key drivers; and Section D: CSFs.

Section A: Respondent's experience: This section contained only one question which asked respondents if they have ever used RFID on their project. The survey questionnaire was designed that only respondents who select "Yes" to this question are allowed to continue the survey. This is to ensure that the data collected is only from professionals with experience in using RFID.

Section B: Respondent's profile: This section was used to obtain relevant information on the respondents. The section contained two questions: Question 1 asked respondents to indicate their type of organization (commercial GC, residential GC, Subcontractor, Architecture/Engineering, etc.) and Question 2 was used to collect information on respondents' job positions (project manager, architect, construction manager, etc.)

Section C: Key drivers: This section contained one question and was used to rate the level of importance of the 12 identified key drivers from literature review and interviews. The aim is to solicit the main reasons why companies would adopt and implement RFID technology. The questionnaire was based on the five-point "Likert scale" of importance ranging from one (1) to five (5) where 1 = "unimportant", 2 = "little importance", 3 = "moderately important", 4 = "important", 5 = "very important".

Section D: Critical success drivers: The fourth section also contained one question and was designed to collect data on the level of importance of the 15 success factors identified from literature review and interviews. On each of the 15 factors, respondents were asked to indicate the extent to which that factor is important to the successful adoption and implementation of RFID. Same as the Section C, the questionnaire was based on the five-point "Likert Scale" of importance ranging from one (1) to five (5) where 1 = "unimportant", 2 = "little importance", 3 = "moderately important", 4 = "important", 5 = "very important".

Distribution The survey questionnaire was administered online and was mainly directed towards project managers, architects, engineers, general contractors and construction managers. To reach the respondents and garner participation from the industry, the survey was advertised through distribution lists of several professional associations. These include the Construction Management Association of America, Associated General Contractors, American Institute of Architects and National Association of Home Builders. As the survey was available to the entire groups of associations, it is hard to determine the sample size. The authors checked the IP addresses and respondent IDs for repeated entries and multiplicity. There were 122 respondents to the survey, but only 52 selected "Yes" for Question 1 to indicate they have had experience with using RFID. This is not surprising considering that the initial literature review indicated that RFID usage in the building industry is extremely low. This makes it more worthwhile to conduct this study and examine the key drivers and success factors. The survey was opened for about 14 weeks from March 27 to June 25, 2018.

Data analysis

The data collected on the key drivers and success factors were first analyzed for reliability. The test for homogeneity or internal consistency was conducted to determine the degree of consistency or dependability. Cronbach's alpha was used for the reliability test. Cronbach's alpha is the most common measure of internal consistency (reliability) and is commonly used for multiple Likert questions in a survey/questionnaire that form a scale to determine if the scale is reliable (Laerd, 2018). The data were analyzed in SPSS. It is important to determine the reliability before performing any further analysis on the data. The Cronbach's alpha for the key drivers and success factors are 0.952 and 0.954, respectively, indicating a high level of consistency for both scales.

Relative Importance Index (RII) was used to analyze the data from Sections C and D of the survey. The RII was used to rank the key drivers and success factors. From the ranking assigned to each factor, it is able to identify the most CSFs of RFID adoption and implementation in the building construction industry.

RII or weight is a type of relative importance analyses. The RII has been used in many studies to evaluate the comparative importance of a single item to others. According to Johnson and Lebreton (2004), RII aids in finding the contribution a particular variable makes to the prediction of a criterion variable both by itself and in combination with other predictor variables. The following formula was used to calculate the RII:

$$RII = \frac{\Sigma W}{A * N}$$

where W is the weighting given to each factor by the respondents and ranges from 1 to 5; A is the highest response integer (5); and N is the total number of respondents. The individual responses from the respondents were analyzed in Microsoft Excel using the above formula. The five-point Likert scale was transformed to RII for each factor. The RII value ranges from 0 to 1. The closer the value is to 1, the more important is the factor.

Results of data analysis

The review of the literature and the interviews results, the key factors and CSFs were revised, and some were consolidated resulting in 12 key drivers and 15 CSFs. The 12 key drivers and 15 success factors used for the survey are presented in Table III.

Respondents' profile

Figure 2 presents the different types of the respondents' organization. Majority of the respondents (31 per cent) work for residential GC, followed by architecture/engineering firm (23 per cent). About 8 per cent indicated they work for government/public agency, and 8 per cent also work for subcontractors. The different positions of the respondents are presented in Figure 3. Half of the respondents are project managers.

Key drivers and success factors

The relative importance analysis was conducted to rank the key drivers and success factors. The results of the analysis are presented in Tables IV and V for key drivers and success factors, respectively.

Table III.
Key drivers and success factors of RFID in the building construction industry

Key drivers	Success factors
Improving materials and equipment tracking	Management support and commitment
Improvement of labor tracking	Clear RFID strategy, needs and benefits
Resource management automation	Strong motivation for improvement
Productivity improvement	Adequate funding
Safety improvement	Proper planning
Optimization of resource usage	Proper staff training
Increase profitability	Integrating RFID into existing IT architecture
Waste reduction (lean processes)	Partnership with competent RFID providers
Reduction of operation cost and time	Having measurable business benefits (ROI, etc.)
Inventory reduction	Facilitating equipment vendor's investment
Customer satisfaction improvement	Choice of hardware and software
Theft reduction	Starting with small RFID project
	Using cost-effective reusable tags
	Changes in organizational policies and operation
	Project management (teamwork)

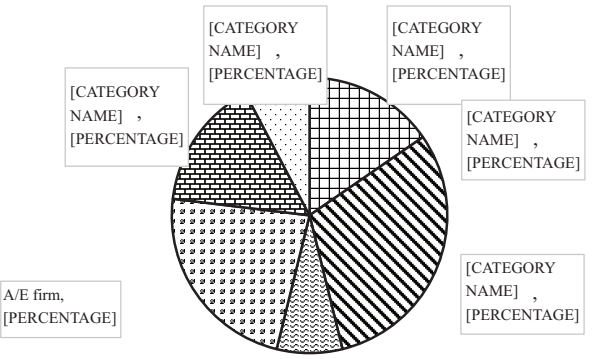

Figure 2.
Types of organization

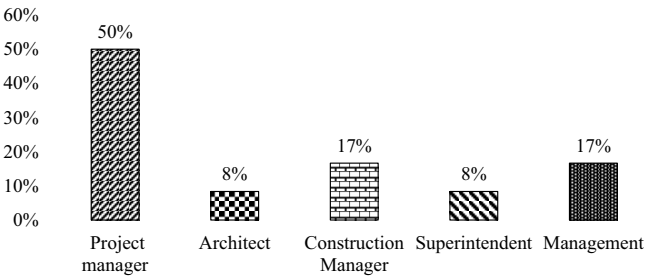

Figure 3.
Respondents' positions

Discussions

Key drivers

From the survey, the top five reasons why the respondents use RFID are "productivity improvement" (ranked first), both "increase profitability" and "safety improvement" (ranked second), both "customer satisfaction improvement" and "improving materials and equipment tracking" (ranked third), "reduction of operation cost and time" and

Key drivers	RII	Rank
Productivity improvement	0.92	1
Increase profitability	0.87	2
Safety improvement	0.87	2
Customer satisfaction improvement	0.85	3
Improving materials and equipment tracking	0.85	3
Reduction of operation cost and time	0.83	4
Optimization of resource usage	0.83	4
Improvement of labor tracking	0.82	5
Waste reduction (lean processes)	0.80	6
Resource management automation	0.78	7
Theft reduction	0.78	7
Inventory reduction	0.75	8

Table IV. Ranking of key drivers

Success factors	RII	Rank
Management support and commitment	0.92	1
Clear RFID strategy, needs and benefits	0.88	2
Strong motivation for improvement	0.87	3
Proper planning	0.87	3
Proper staff training	0.87	3
Adequate funding	0.85	4
Project management (teamwork)	0.82	5
Having measurable business benefits (ROI, etc.)	0.82	5
Integrating RFID into existing IT architecture	0.78	6
Partnership with competent RFID providers	0.77	7
Choice of hardware and software	0.75	8
Changes in organizational policies and operation	0.75	8
Starting with small RFID project	0.72	9
Using cost-effective reusable tags	0.72	9
Facilitating equipment vendor's investment	0.68	10

Table V. Ranking of success factors

"optimization of resource usage" (ranked fourth) and "improvement of labor tracking" (ranked fifth). The least ranked reason is "inventory reduction" (Table IV).

On the Likert scale, 95 per cent of the respondents rated productivity improvement as very important (5). This is very significant considering the fact that the construction industry has an intractable productivity problem, and respondents over the years have indicated that they are willing to participate in activities related to improving construction productivity Arditi and Mochtar, 2010. While some industries such as manufacturing and retail have reinvented themselves to improve productivity, the:

> [. . .] global labor-productivity growth in construction has averaged only one per cent a year over the past two decades compared with growth of 2.8 per cent for the total world economy and 3.6 per cent in manufacturing (Barbosa *et al.*, 2017).

Technology such as RFID has the potential of improving productivity, and it is evident that the respondents are relying on RFID to help in this regard. Use of RFID by construction workers can quickly locate equipment, tools and materials on site and spend less time to locate materials on transit – a condition which increases productivity and in turn reduces costs and time while, at the same time, increasing profits.

RFID has been proven to increase the profit margins of construction companies. According to Shin and Eksioglu (2014), RFID can improve the profit margins of construction companies through inventory efficiency, cost efficiency and low-level inventory ratio. As companies seek to improve their profitability, this drive is essential in adopting the technology. RFID is also being used to ensure worker safety on the jobsite. These include readers activating an alarm when a worker wearing a tag approaches a potential hazard area and tracking location and maintenance of various fall protection systems. Safety should be a top priority for all construction companies and the respondents are relying on RFID to improve safety on jobsites. Safe jobsites cut on lost man-hours due to injuries which will help in increasing profits and improving company reputation.

The capability of RFID technology to send and receive and store data is of great importance in improving construction project productivity as compared to traditional tracking technologies such as bar code and scanning devices. It is important to state that improvement of materials and equipment tracking, improvement of labor tracking and reduction of operation time will ultimately lead to improved productivity. Material and equipment tracking using RFID will help reduce the amount of time that construction workers spend trying to locate materials, equipment, and tools that they need for a specific task. Furthermore, tracking materials on transit helps in scheduling construction labor to avoid idle labor as workers wait for material to be delivered. The most important recommendation from this section is that vendors and RFID companies interested in extending and expanding their services to the building construction industry should focus more on productivity improvement as it is the most important driving force for using RFID.

Critical success factors.

From Table V, the 15 critical factors to the success of RFID in the building industry were ranked using the relative importance index. The factors are discussed further in this section.

Management support and commitment. According to the respondents, the most CSF is management support and commitment. The RII is 0.92 out of 1, indicating its critical importance. As a new technology in the building construction industry, management's decision to support and commit the necessary resources is crucial to the success of RFID technology implementation. Management support systems encompass many of the other success factors. Having top management support and commitment include proper project governance and leadership, funding the project, managing risks, communicating strategies to employees, establishing reasonable objectives and monitoring progress of the project. A smooth implementation process is critically hinged on management support and commitment.

Clear radio frequency identification device strategy, needs and benefits. The second ranked factor is having a clear RFID strategy, need and benefits. For every project to be successful, it is important that a well-thought out strategy for implementation is carved to suit the needs of the company. When the company and all employees are aware of the benefits the technology will bring to the company, it is easy for everyone to contribute to its success.

Strong motivation for improvement. A company's desire to improve is important to adopt and implement new technologies. Continuous motivation to improve performance is necessary to achieve the benefits of any technology including RFID. It is therefore important

for organizations to motivate all levels of employees to ensure a company-wide commitment to improvement.

Proper planning. No project can be successful without adequate planning. Proper planning and preparation prevents poor performance. Planning should primarily provide an orderly step by step process of achieving the end product or goal. RFID implementation should be thoroughly planned to improve its success from its adoption through to its disposal for upgrade. The planning should focus not only on financial needs, but also on time, users, type of RFID technology, etc. Planning for RFID should address the objectives, milestones, progress tracking, model and type or RFID, maintenance, etc.

Proper staff training. Although RFID technology seems very easy to use, it is important to provide proper training to ensure that all employees are familiar with the technology and understand how the system operates. Through training, the technology can easily be assimilated, and this will boost its usage. Training will also elevate the employees' skill level and knowledge making it easy to utilize the technology.

Adequate funding. The importance of financial resources to the success of every project cannot be overestimated. RFID implementation costs money, and as every company's need may be different, it is important that adequate funding is committed to buy and implement the right RFID technology. Continuous improvement of the system will also require the commitment of the needed funds to upgrade, train and build capacity.

Project management (teamwork). Several groups generally make up a construction team. It is important that the team of subcontractors and general contractor employees work together to ensure the success of RFID technology. Teamwork may lead to human synergy through trust building, shared goals and by understanding each member's duties and responsibilities towards the success of RFID implementation.

Having measurable business benefits (return on investment). Studies in other industries as presented above in the literature review have shown that RFID has several benefits including ROI. It is no secret that companies will be hesitant to implement if they are not sure of the ROI. It is important that each company evaluates the benefits and develops an objective strategy to assess and measure these benefits. Being able to know whether the benefits are being achieved or not will help in making the required adjustments to improve performance.

Integrating radio frequency identification device into existing information technology architecture. The sixth ranked factor considered to improve the successful implementation of RFID technology is integrating the technology into an existing information technology (IT) system. As most companies already use some form of IT structure, incorporating the RFID into it streamlines the system rather than having two parallel systems. Using existing infrastructure also reduces amount of hardware, such as computers, needed for implementation.

Partnership with competent radio frequency identification device providers. For a successful implementation of RFID technology by building construction companies, the RFID infrastructure has to be supported by competitive providers. The companies will offer both the hardware and software needed and the support needed for operation. In case a problem occurs during implementation, good providers will offer trouble shooting support systems to the construction companies.

Choice of hardware and software. The choice of an RFID system should be compatible with staff capabilities to ensure that potential users have no problems in adapting it. The

choice will also consider the company's existing infrastructure such as the available computers and how much modification needs to be incorporated to support the system.

Changes in organizational policies and operation. Different organizations and companies operate within certain policies. Therefore, to incorporate a new technology, a company will have to change those policies to allow a change in the way the company operates. The use of RFID within an organization can affect different departments including IT, Procurement, staffing, management, among others. The policies need to be adjusted to accommodate these changes. This might even include hiring new staff to support the technology. In building construction companies, many departments are dependent on each other and more so on the internal operating policies of the company. Therefore, coordination among them will lead to effective implementation of RFID.

Starting with small radio frequency identification device project. By starting the use of RFID in a small project, the organizations can reduce risk and any problem that can be associated with new technology. This will provide staff with a learning curve for improvement and streamlining any needs that may arise from there. Through the RII of 072 derived from the survey respondents, those surveyed agree that this factor is of importance in realizing the benefits of RFID use in building construction.

Using cost-effective reusable tags. The use of reusable tags offers both economic and environmental benefits. The benefits of these reusable tags help companies to better track material and/or equipment and tools as they move through the supply chain. This will in turn impact positively on the return on investment for the companies through an effective supply chain management and analysis of the data provided. Another benefit to the company will be reduced labor costs for one-way tagging applications.

Facilitating equipment vendor's investment. Currently, the RFID equipment is still expensive. As such, it is encouraged that building construction companies that want to implement the RFID technology should identify an RFID equipment vendor and negotiate to collaborate with it. The vendor company can get involved in the project by leasing out the equipment to the building construction company with the understanding that the company will consider buying the RFID equipment after the successful implementation. The company can also benefit from the vendor's support services including providing spare servers and computer systems for implementation.

Conclusion and recommendations

Over the past decade, there has been a rapid growth of the use of RFID technology in different industries including retail, manufacturing, retail and health-care. In the construction industry, the use of RFID is limited and has reportedly been on a smaller scale and mostly in transportation and pipeline projects in developed countries such as the USA. It is surprising that there is only a limited use of RFID in the construction sector despite the benefits associated with this technology. Therefore, this research contributes to the body of knowledge by providing an exploratory framework that can be used by building construction company executives and managers to provide justification for deciding to implement RFID in their projects. Furthermore, the study provides a basis for further investigation on the emerging issues regarding RFID use in the construction industry in general.

In this research, the authors reviewed in the literature the key drivers of RFID use and the CSFs of their adoption in different industries. The key drivers and CSFs identified were further investigated through expert interviews and further through an online survey. The findings revealed on a ranking scale, the key drivers and CSF on the order of their importance. It is not surprising that productivity improvement ranks number one in the key

drivers. Productivity has been an issue in building construction sector and it affects both the cost and scheduling of projects. Use of RFID technology will save time in avoiding loss of construction material and labor hours and helping in scheduling by tracking materials as to when they will be delivered in the jobsite. RFID technology also helps in improving productivity by reducing some redundant processes through automation. Construction practitioners are out to make money and therefore, increasing profitability was ranked number two according to the findings. Cutting down on redundant processes such as bulky hard copy documentation, locating materials on site, tacking material on transit among others will reduce waste and thus increasing profitability margins. In general, the findings reveal that the key drivers point to those factors that could benefit the companies to improve processes of project delivery and achieve maximum benefits.

In terms of CSFs, research findings point to management support and commitment as an important factor. This means that for RFID technology to succeed, it must have the commitment of the management. This is even more important when it comes to decision making in terms of initial costs and sustaining the process. This is because implementing RFID may include hiring of new staff, training, buying of infrastructure among other things that require the support and commitment of the management. The implication of this research is therefore to provide a framework for company executives and managers to use as a justification to implement RFID. This framework and justification ties together all the key drivers and CSFs together because they all go back to what the company will benefit out of their investment in RFID. Furthermore, it will also provide construction managers and other construction project participants with a tool that they can use to successfully implement RFID in residential/commercial construction projects.

This research paper is limited on just the identification and exploration of key drivers and CSFs of RFID adoption in building construction industry. To provide more justification to this, a study connecting key drivers, CSFs and benefits through case studies is recommended. This will even be more interesting, if case studies will be conducted to look at the return on investment in terms of tangible and intangible benefits of RFID. Such case studies could be used by industry practitioners as success stories for implementation of RFID in the building construction industry.

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