Auto ID-Bridging the physical and the digital on construction projects

Auto-ID - Bridging the physical and the digital on construction projects

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CIOB

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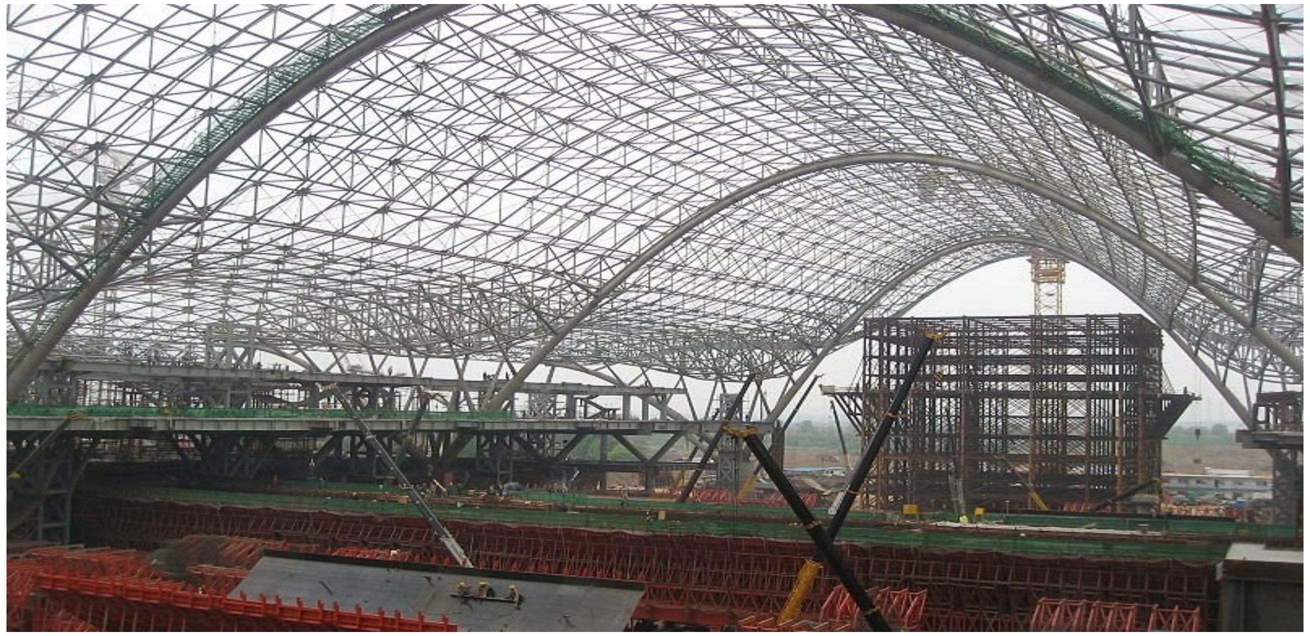
"Auto-ID can provide cradle-to-grave traceability"

Introduction

Automatic-identification (auto-ID) technologies are part of everyday life, yet the construction industry has been slow to adopt them. Lots of reasons can be offered for the lack of take-up, ranging from too expensive, not enough time to learn the new technologies, to lack of opportunity. However, it is a robust technology that is transforming business processes, offering an opportunity to use data and information more efficiently, reliably, and effectively. The travel, retail, finance, and manufacturing sectors all use auto-ID technologies in their business. Car production lines could not function as efficiently as they do without auto-ID, similarly air travel would be more difficult without the luggage, freight, and boarding passes being automated. Construction needs to be at the forefront of the advances in auto-ID, demonstrating that it is an exciting and innovative industry.

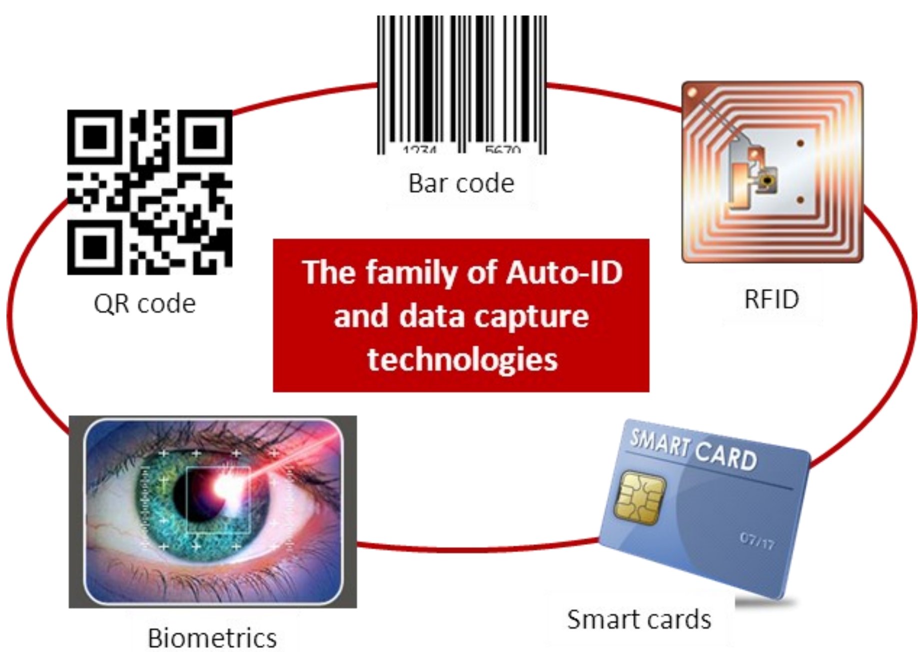
This report looks at how auto-ID has evolved and how it can be used in the construction industry and across projects from the perspective of all the stakeholders, from owners to design consultants, contractors and the supply chain. It could help to improve efficiency, reduce costs, ensure quality, protect the environment, and enhance safety.

Auto-ID is an enabling technology, where three categories of effects can be identified: automational, informational, and transformational. Data and information are at the core of every consultancy and construction business where it is necessary to use data and information more effectively.



The technology is equally applicable to small, medium and large enterprises. It can be affordable, available, reliable, robust and user-friendly. It does not require a large IT department to implement it; it requires motivation, an open mind and a desire to improve the business. With a little effort, the first steps can be taken. Progress in mobile technologies has opened up greater possibilities for on-site use.

Construction projects have always been a challenge to deliver safely, on time, on budget and to the right quality. However, there are new pressures to ensure sustainability, safety, and ethical responsibility. There is more legislation imposed by government on issues such as planning gain, disposal of waste, and landfill tax. The office and the job site have to handle more data and information, so there is the need for real-time information, visibility and traceability. Accurate information is needed to track materials, workers, machinery and site progress. Auto-ID is a technology which will transform the way that projects can be delivered.



> *"We live in an increasingly smart planet where everything is instrumented, interconnected and intelligent. Businesses need a common set of data standards so they can drive intelligence from a strong foundation."*
>
> ***IBM***

History and development of Auto-ID

Auto-ID technologies explained

Auto-ID technologies are not new. Bar coding has been used for over 40 years, but new technologies are constantly being invented, refined and used. The quick response (QR) code is more commonly seen on adverts and publications and allows somebody to access the linked website by scanning it, with a smart phone and the appropriate app. More and more people are becoming familiar with RFID technology; almost everyone today has at least one item with RFID (e.g. an Oyster card). Biometric information is being developed to improve security on site. Workers can use a finger or palm print to gain access to information or to the job site.

Auto-ID can provide cradle-to-grave traceability that permanently marks items which can be verified from their manufacture, to site production, and through to use. It has the ability to:

- Track - in the present.
- Trace - from the past.
- Control - into the future providing continuation.

There has been considerable improvement over the past 20 years in the technology, its reliability, the cost of the hardware and software, and the availability and ease of use. Auto-ID is a collective term for systems which allow automatic identification of items. Auto-ID systems use either labels or tags or embedded data to store electronically-readable information. This information, in its basic form, provides a means of rapid identification and recording. The most commonly used auto-ID technology is bar coding, but other auto-ID solutions such as magnetic strips, smart cards, optical character recognition, and radio frequency identification (RFID) have also attracted considerable attention in recent years.

Auto-ID technologies, which have transformed the retailing and manufacturing sectors, could be used to address data capture problems. They could provide real-time information, instead of "driving using the rear view mirror". Auto-ID technologies involve 4 basic elements:

- An object which needs to be monitored or tracked in some way, such as tools, machinery, materials, and even human beings on a jobsite.
- A label or tag which is attached to the object and which identifies or describes the object in some way. Through this process, the object is converted into smart objects (SOs). The purpose of SOs is to create an intelligent environment within the typical production sites such as shopfloors, warehouses, the logistic and supply chain, and jobsites. SOs are building blocks for an intelligent environment, in which they are able to sense and interact with each other.
- A reader, or the middleware, which is capable of reading the label/tag electronically or relaying the information to a back-end system.
- A back-end system, where data is manipulated and stored, and forms the data resource for the system users. This system collects input from users or other systems for processing. The construction of the backend system is very application-specific and can range from one application to another.

The core concept of auto-ID is to associate the physical item with its history/data, thus allowing important data to be obtained/stored/retrieved by different parties at different times. A material/component's digital identity may be located on a tag or a bar code. It is the role of auto-ID to access that information and extract the information (McFarlane and Sheffi, 2003), for use in say, inventory management, supply chain management, or facilities management.

The global trade association for automatic identification, AIM Global, identify two common goals of auto-ID technologies:

- Elimination of errors in the identification/data collection processes
- Reduction in the time taken to capture data.

Auto-ID is a fundamental enabler to streamline business processes, reduce inventories and increase the productivity and quality of business operations. It is a system and a technology that collects and assembles data, sometimes converting it into information. The ability to gather, store, access and analyse data has grown exponentially over the past decade (Shah et al., 2012). Gathering data for the sake of it is expensive, the key is its usefulness and timeliness.

Auto-ID technologies can identify, track, record, store and communicate essential business, personal, or product data.

Different technologies in Auto-ID

Bar codes

Bar codes use a labelling system composed of a pattern of light and dark bars producing a graphical form of binary logic which can be scanned and interpreted by computers.

First generation

Bar codes, first implemented in 1974, transmit a small amount of information that identifies the manufacturer and links to a description of the object. The original bar codes were one-dimensional, but 2-D bar codes are now used, providing much more information. There is now 3 generations of bar codes - see figure overleaf. The first generation of linear or ID bar codes were optical machine-readable labels scanned by a laser diode barcode scanner. They were heavily reliant on the use of a database that stored the data and information; without access to the database, the bar code system is of little value. The challenge was that the manufacturers often used a database that was different to the retailer. Machine-readable symbols fall into the category of linear bar codes, stacked bar codes, 2-D symbols and Optical character recognition (OCR).

Second generation

The second generation used 2-dimensional bar codes to embed data into the tag. 2-D bar codes make use of the horizontal and vertical dimensions to store data. PDF417 is a type of 2-D bar code symbology. Since bar codes were first introduced, the desire has been for the code to carry more data per unit area, thus achieving higher data density. Auto scanners have replaced the light pen.

Third generation

The quick response (QR) codes enable fast data access, often used in conjunction with smart phones. The bar code reader on the phone can interpret a URL, which directs the browser to the relevant web site. QR codes are included on products that direct the user to print, pictures and video. This has huge potential on site where the site operative can get more information about the product, fixings, the tools required and the safety guidelines.

Bar code technology has the advantage of being low-cost, sufficiently robust for most applications and capable of displaying human-readable information beneath it. Physical design considerations of bar code systems, including size, printing method, physical medium and method of attachment, are also important issues but are outside the scope of this report.

An aspect of bar coding is how the materials and components can be marked. Labels can be paper- or plastic-based. However, some equipment needs to be permanent, such as on vehicles. Direct marking using 2-D symbols is used on metal, plastics, glass and rubber with the 2-D code etched onto the material as a permanent record.

Criticisms of bar-coding systems in the past have included the way labels can be easily damaged, that the bar code cannot be read in direct sunlight, and that it cannot withstand harsh conditions. Furthermore, bar codes have two main limitations: the need for a direct line of sight from the scanner to the bar code and the ability to read only one code at a time. The volume of the data that can be stored is limited. Only numbers and characters can be used in barcode and it has a limitation of 20 characters.

However, all these criticisms have mostly been overcome, mainly through improvements in technology. For example, QR codes can increase the data volume to be stored. Radio frequency identification (RFID) technology provides a good substitute in areas where bar coding is inadequate, notably the ability of the tag to accommodate updated information (i.e. writeable as well as readable) and large amounts of information on the tag. These technologies will be described further in the following sections.

"With a swipe of the hand on June 26th 1974, at a supermarket in Ohio, a pack of chewing gum became the first retail product to use a scanner and a bar code"

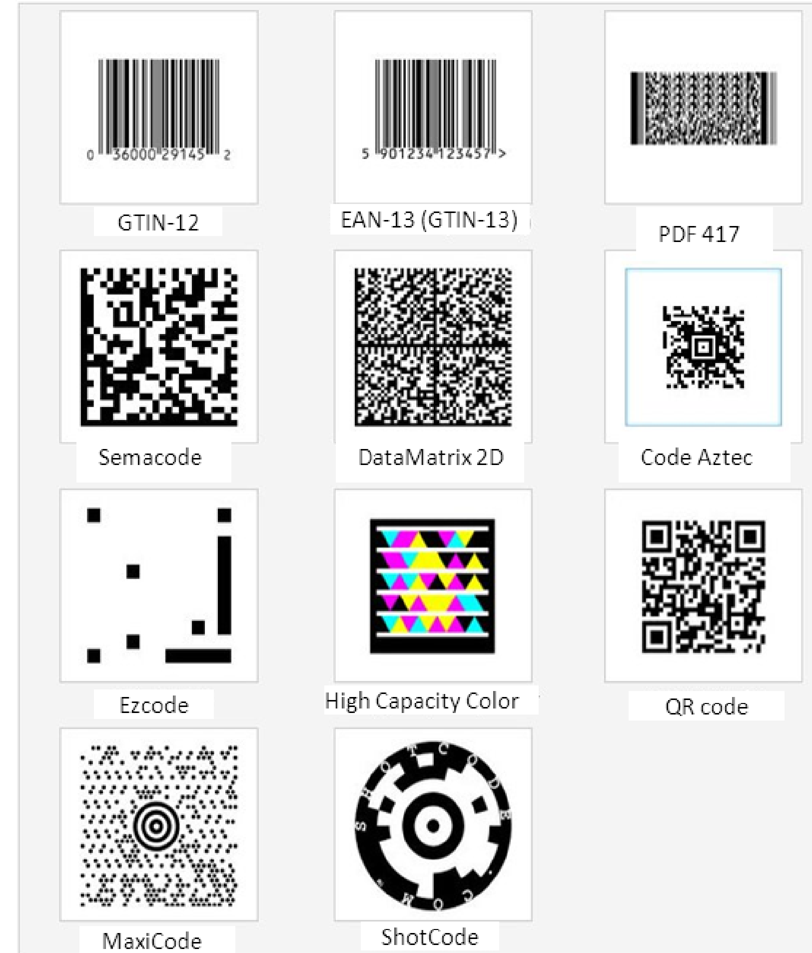
Auto-ID technologies enable automated processes and improve overall operational control and management.

Implemented properly they can:

- *Improve resource efficiency*
- *Eliminate human errors*
- *Speed up processes*

"Reliable information exists, but it is hard to locate . . . Fewer than 44% of employees say they know where to find the information they need for their day-to-day work."

(Shah et al., 2012)



Bar code evolution - from 1-D to 2-D

Quick Response (QR) code

A Quick Response (QR) code is an example of a 2-D matrix code. It was first used by Toyota in 1994 to track vehicles during manufacturing. Today it is more commonly seen on adverts and publications and allows somebody to access the linked website by scanning it, with a smart phone which has the appropriate app.

Similar to a 2-D bar code, QR codes are easy and free to make. The amount of information that can be stored depends on the type and the density of the blocks. Therefore, they have the ability to store and display more information including text, contact information, event information, and URLs which may have videos and images.

The weakness of the QR code is that it is a one-way information transmission. Another problem is information security, all smart phone owners with the right app can read a QR code. Therefore sensitive information should not be stored in QR codes, although any website to which the user is taken could have the necessary security.

Case study - London 2012 Olympics

Biometrics were used on site for timekeeping, security and health and safety records. Construction workers at all the venues had to pass through a 2-tier biometric system using palm and facial recognition technologies. The system had to be robust enough to process up to 10,000 people as they passed through specially constructed barriers. It was described as the UK's largest and most expensive security operation.

During the enrolment process all workers had their hand scanned to enable access to the Olympic Park. A 3-D digital photograph of their hand was taken and linked to their photographic site pass. The unique size and shape of a hand is matched to the site pass to enable access. The data is encrypted, stored securely and only used for access to the site during the construction work, in accordance with the Data Protection Act.

UK companies using biometrics for site/personnel management include Lend Lease, Carillion and BAM. BAM uses human recognition systems to: cover worker time and attendance; incidents and accidents; health and safety accreditations; and emergency roll calls.

By using 'real time' biometrics, a 20% improvement in attendance can be achieved, compared to a paper-based system. This saving, and the 20-40% improvement in the accuracy of reported site working hours, is a good basis for a business case for the increased use of biometrics on constructions sites.

Optical Character Recognition (OCR)

Optical character recognition, usually abbreviated to OCR, is the mechanical or electronic conversion of scanned images of handwritten, typewritten or printed text into machine-encoded text. It is used to digitise books and documents into electronic files, to store it more compactly, display or print a copy free of scanning artefacts, and apply techniques to it such as machine translation, text mining and text-to-speech. OCR makes it possible to edit the text, search for a word or phrase

Biometrics

"Biometrics is the science of establishing the identity of an individual based on the physical, chemical or behavioural attributes of the person." (Jain and Ross, 2008, p. 1). Biometrics and identity management are closely linked. They are a powerful set of tools increasingly used for security purposes, including customs and computer security. Eye/iris scanners are commonplace in major airports and the US Homeland Security uses iris and fingerprint recognition.

There are a number of technologies that make up the family of human recognition systems:

- Iris recognition
- Finger scanning and electro-optical fingerprint recognition
- Face recognition
- Voice recognition
- Hand recognition
- Vein recognition
- Behavioural analysis e.g. typing rhythm, gait, and voice

Biometrics involves the measurement of unique physiological human characteristics. They have a huge advantage in that, unlike cards and passwords, they can never be forgotten, lost or copied. But biometrics is still in its infancy because of the confluence of biometrics with identity management and the need to develop consensus on social, legal, privacy and policy issues.

QR code - scan this to access the CIOB website

Smart cards

Smart cards are sometimes confused with magnetic stripe cards, such as a credit/debit card which comprise iron-based particles (each particle is a tiny bar magnet where information is stored) in a plastic-like tape. This technology has been in existence since the 1970s.

Smart cards use an embedded microchip, which is an integrated circuit. They can store much more data than a magnetic stripe card. Some smart cards can include programming and support multiple applications.

Contactless smart cards are often confused with RFID cards such as the Oyster card used on the London Underground and buses and the Construction Skills Certification Scheme (CSCS) card which provides a simple way of recording site workers' competence levels, which can be checked using a simple smart-card reader. The use of a smart contactless card and the RFID card depends on the level of privacy/security needed.

Radio frequency identification (RFID)

RFID was firstly introduced as a sister technology to replace the barcode system for identifying items. It has been identified as "one of the ten greatest contributory technologies of the 21st century" (Chao et al., 2007, p. 268). RFID has its foundations as far back as WWII, where its predecessor was the IFF (Identification Friend or Foe) system. This system allowed the Allies to identify incoming planes. A major obstacle for RFID technology has been the development of a suitable power source; it took almost three decades to devise an internal power source.

RFID is a technique used to identify objects by means of electromagnetic waves. An electronic responding label, known as a tag or a transponder, consists of an antenna and an integrated circuit. An RFID system comprises three main components: 1) An RFID tag which is located on the object to be identified. The tag is often formulated by a microchip which stores data and has an integrated antenna serving as a transmitter. 2) An RFID reader, or transceiver, which may be able to read data from, and write to, a tag., and 3) A back-end system, which receives, stores, forms, and manipulates the data transmitted from the reader to respond to information uses, e.g. decision-making.

There are two types of RFID: passive and active. The former has no integral power sources but relies on the reader to supply power for wireless communication. The latter has a power source installed. It can store a relatively large amount of data. For example, a passive RFID's memory can vary from 128 to 256 bytes while the memory of an active RFID can range from 32 to 128 kilobytes (Goodrum et al., 2006). These data can be encrypted to increase data security. It is possible to read data from multiple tags at one time, thus increasing the efficiency of data processing. In comparison with a barcode or magnetic system, no direct contact between anRFID reader and the tagged item is needed as it uses radio waves which range from 125 KHz - 5.875 GHz. The reading distance can be as great as 15-25 metres if powered by an active RFID (Goodrum et al., 2006). In addition to reading data, it is possible to write data back to the RFID tag. This greatly increases the interaction between people, product and process.

The use of RFID across many different industries is increasing. It rose from 0.6 million units bought in 2005, to 1.2 million in 2006 and is expected to reach 700 billion in 2015 (Vandagraf International, 2007). A more recent report forecasts the global RFID market will grow at a compound annual growth rate of 18%, reaching US$19.3 billion in 2015 (RNCOS, 2012). The market for cheaper chipless RFID tags is growing at a faster rate (CAGR of 27.1%); the RFID market is forecast to reach US$30.3 billion in 2024 (RFID World Canada, 2014). A chipless tag does not store a serial number on a silicon microchip in the transponder but uses plastic or conductive polymer or a material that reflects back a portion of the radio waves beamed at them (RFID Journal, 2013).

A tag can identify and locate an asset/material component as well as communicating when it was last used/checked and detect who used the asset last. Tags have the ability to report information in real time, such as locating people or plant/equipment on site. Wireless communication has enabled huge developments in the use of RFID and with everyday technology such as a mobile phone or laptop the need for expensive/permanent communication infrastructure on site is reduced. The scanners required to read the tags have become more affordable. Advances in the technology means that some high-performance tags can be mounted on metal and read up to six metres away.

The differences between barcodes and RFID	
Barcode (Linear or 2-D)	RFID
A Barcode is printed and cannot be modified unless a new barcode is reproduced.	Read/Write RFID tags can be reprogrammed (tag data can be appended, modified, deleted).
Simultaneous reading not feasible.	Several tags can be read simultaneously.
Barcode reading requires line-of-sight contact between the reader and the barcode	RFID tags do not require a direct line-of-sight contact. Identification is independent of the position and arrangement of the tags. Tags can be read through wood, plastic and a lot of other materials except metal; the tag can be hidden.
A lot of inexpensive goods are not uniquely identified.	Tags can uniquely identify the products. For example, each bottle in a pack has a unique Electronic Product Code (EPC).
The barcode label space is limited.	Tags can retain a lot of additional functions (e.g. control, write/read) and a large amount of information. Several kilobytes of data can be stored by special tags.
Barcode scanners and the label need a clean environment	Effective in dirty environments, around chemicals, moisture and high temperatures. Not for UHF which is sensitive to humidity.
Barcode technology is very commonly used across industries because of its maturity and proof of quality.	RFID is a more recent technology. For supply chain management, the technology is still in the process of ongoing standardisation and harmonisation.

The tags are read by fixed or handheld readers. Fixed readers are generally larger devices that have a greater range than handheld devices. The fixed readers can be built into conveyors or benches, or toll booths. The operation is hands-free, whereas hand-held readers have flexibility. Information from the reader is uploaded on to a system for processing.

From the original inductively-coupled RFID tags, later innovations of the technology included active, semi-active and passive RFID. These had greater capabilities but, in the early days of the newer tags, the price was often the prohibiting factor, particularly compared with the low-cost bar code technologies. However, research has shown that there is a continuing reduction in the price of tags.

The table above summarizes the strengths and weaknesses of prevailing Auto-ID technologies. The competition is basically between barcode and RFID technologies, where the latter seems to have all the advantages. However, the cost and reading accuracy of RFID are still weaknesses that need to be fully overcome.

Whereas barcodes have to be seen and deliberately read, RFID tags can be hidden and detected without anyone realising what is happening.

Auto-ID applications

Auto-ID in industry

Auto-ID technologies such as bar coding have been used in retailing and manufacturing for many decades. For example, the car industry uses it as a low cost method of data storage as virtually every car on the production line can be different. Automated manufacturing and logistics controls demand knowledge of each vehicle's customer specification. Each vehicle is identified by a data carrier (a read/write tagging device or a metallic bar code tag) which machine-controlled programmes use at each individual station through the body shop, paint shop and assembly line.

Airports have radar sensors that use radio frequencies to automatically track what is going on in real-time. The information from the radar sensors feeds into the air traffic control system, helping it to make real-time decisions and giving them real-time visibility and measurability. In the same way that radar sensors provide visibility, a company needs a business radar to see what is happening in operations, digitally, automatically and in real time.

Airbus described its value chain as 'costs and profits in motion'. It is a good description of the construction supply chain where everyone should (needs to) be connected digitally. Both the costs and the profits are spread along the value chain rather than being limited to a particular function. The same applies to waste, which is not limited to company boundaries. A whole-life view needs to be taken to maximise the benefits for all stakeholders. The innovative approach used by Airbus has been directed at logistics, tool management and the tracking of work in-progress, to name just a few. Each of the projects has provided financial benefits in a relatively short time. Increased automation has improved productivity and quality (Roberti, 2011).

RFID in industry

Walmart is a major player in the promotion of RFID technology. Using its dominant position in the industry, it requires its upstream top suppliers to adopt RFID technology which will facilitate operations towards the downstream (e.g. distribution, wholesale, and retail) (RFID Journal, 2003; Huang et al., 2008). RFID is also widely used in facilitating:

- electronic transaction (e.g. Toll collection A, Octopus card (Hong Kong), or Oyster card (London)
- logistic and supply chain management (e.g. the internet of things)
- manufacturing and assembly (e.g. the assembly of cars)
- express service (e.g. American Express)
- scientific research (e.g. tracing snakes and migratory birds);
- medicine (e.g. identifying a specific patient), and
- security (e.g. access control).

It is envisaged that the technology, with its superior capability to provide real-time information, will significantly improve the effectiveness and efficiency of the above processes.

The tracking abilities of RFID are used in many industries. For example, pharmaceutical companies have embedded RFID chips in drug containers to track and avert the theft of highly controlled drugs. Airlines use RFID tags to track passenger bags; many tolls roads use RFID technology to collect fees without the need for toll booth personnel; ExxonMobil, and other petrol companies, uses RFID technology for its "SpeedPass" which instantly collects payment at garages using a tag on a driver's keychain, and; the UN uses RFID technology to track the movements of its personnel. The car and aircraft manufacturers require their supply chain to add permanent RFID tags to all the components. The tags are designed to remain with the parts through their lifecycle. If a component is replaced, both the old and new components will be scanned enabling a record to be kept.

Passive Tag Characteristics:
- *No internal power supply*
- *Mostly read only (data cannot be re-written)*
- *Unlimited life*
- *Usually smaller/lighter than active tags*
- *Mostly cheaper than active tags*
- *Limited read range*
- *Less data storage capability than active tags.*

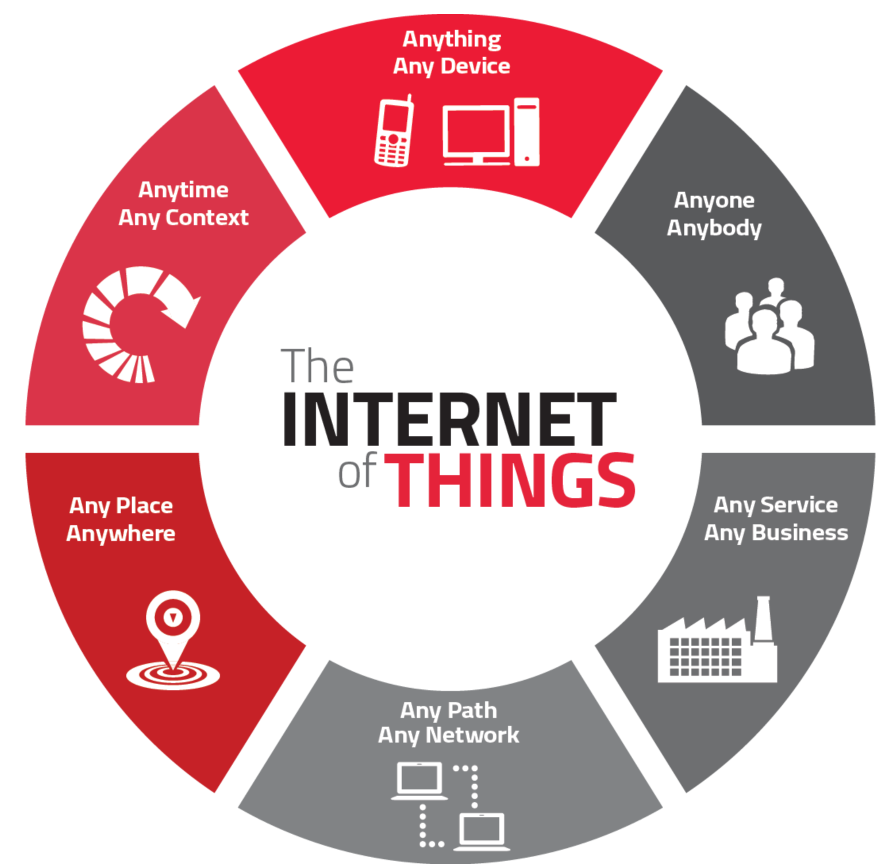
Active Tag Characteristics:
- *Contains internal power supply (battery)*
- *Typically read/write (data can either be fixed or changed)*
- *Limited life (up to about 10 years)*
- *Usually larger/heavier than passive tags*
- *Generally more expensive than passive tags*
- *Longer reading range than passive*
- *Increased data storage capability*

Auto-ID and Internet of Things (IOTs)

Research into RFID is developing. For example, the "Cluster of European RFID Projects" (CERP) was established in January 2007 in order to collect and organise all relevant research results obtained in recent and current European research projects on RFID popularity. In the manufacturing industry, for example, RFID was recognised as an automatic objective identification technology. Notably, research is conducted to investigate how RFID technology can deal with real-time field information, and consequently how it can re-engineer traditional manufacturing systems such as the development of wireless manufacturing, shop-floor assembly configuration, and adaptive assembly planning and control (Huang et al., 2007; 2008a; 2008b).

According to Tajima (2007), the largest area of applications of RFID was logistic and supply chain management (LSCM). Li and Visich (2006) attempted to summarise RFID benefits in LSCM by listing 39 benefits across the supply chain. Tajima (2007) reported that research of RFID in LSCM, either adopting an empirical or an analytical approach, was mainly motivated by the same research question: what is the realistic value of RFID?

In comparison with the studies focused on a given industry, a future vision is to integrate the above process of manufacturing, distributions, and sale, and to achieve the ambition of the 'Internet of Things'. According to Teresko (2003), the 'Internet of Things' refers to a global network of computers and objects in which computers are able to identify and store information on any object, anywhere in the world, instantly.



Source: AGT International (http://goo.gl/lheI1K)

Feature	RFID technology	Barcode	QR code	Magnetic strip
Read rate	Fastest	Slow	Slow	Medium
Write	Possible	Impossible	Impossible	Impossible
Storage capacity	Largest	Smallest	large	Modest
Information security	High	Low	High but easy to copy	Difficult
Ease of positioning for sensing	Easy	Difficult	Difficult	Easy
Cost of a tag	Cheap	Cheapest	Cheapest	Expensive
Ease of obtaining information	Difficult (if encrypted)	Easy	Difficult	Easy (using reader)
Knowledge of items' exact position	Easy	Difficult	Difficult	Difficult

Summary

RFID research in an engineering field is conducted to overcome its many technical and financial hurdles which include its relatively high cost, accuracy of information read/write, reading range/distance. One emerging issue is the low degree of standardization. There is no global public body that governs the frequencies used for RFID. The frequencies used in one country are currently incompatible with those in other countries. There is no standard information structure that facilitates sharing among supply chain partners although RFID-generated product information can provide unprecedented visibility in the supply chain.

The success of auto-ID systems is the use of industry-wide standards and unique numbers that can identify products, components, systems and assets, as happens in the retail industry. For product information there is a need to be connected to the manufacturer for accurate data about product detail, production parameters, and operation/maintenance/recycling. In the retail sector, particularly in the pharmaceutical supply chain management, there are existing data querying systems based on unique product identification approaches. The Electronic Product Code (EPC) is one of these approaches. GS1 (previously EPC Global) is the organisation that offers centralised data services combined with EPC-standard RFID tagging technologies for achieving optimum supply chain practices and to combat counterfeit goods. The data model provided by GS1 can be expanded to serve the virtual component models for the object based modelling tools of the construction sector (Pekericli, 2010).

Auto-ID in construction

The heterogeneity of construction

Auto-ID is applicable across the construction sector through the supply chain from the owner and consultants and plant and materials manufacturers, to contractors and facilities managers. Before going any further, it is necessary to look at the heterogeneity of construction in understanding the urgency of using Auto-ID in this sector.

The construction players

There are many players involved in construction (see figure overleaf) who are frequently geographically dispersed, each using their own IT systems.

They are connected through the project, but they are not integrated. Each player has a different specialism and requires very specific information. The piling speciality contractor does not need the cladding details, he needs geotechnical and structural information. Auto-ID can help by attaching information physically to the component. It sounds easy, but it isn't. Complexity kicks in with the need for robust, reliable and readable systems that are fully understood by everyone in the team. Project collaboration and document management are used to monitor the plethora of data. Digital technology collaboration tools monitor the flow of documents, the flow of communication and process management.

Auto-ID can supplement these processes by enabling information to be embedded and stored. For example, the drawings register will log electronically the receipt of a drawing and the changes to a revised drawing. On the job site, the drawng with the bar code can quickly show the tradesmen, on a hand-held device, the changes to the drawing without having to refer to a computer system.

The sequence (of work)

The RIBA Plan of Work (2013) copes with new build, extensions and refurbishments. Auto-ID can provide an overarching tool that links the Plan of Work sequence by integrating data and information, and by providing the feedback loops that are currently missing. There is little /no feedback to the design team of the facility in use. For civil and environmental engineering, the design sequence will follow a similar path to the building project with more focus on the technical design and production information.

> *"In the traditional business IT departments spend a lot of time focused on the 'T', with too little time spent on the 'I', the information."*

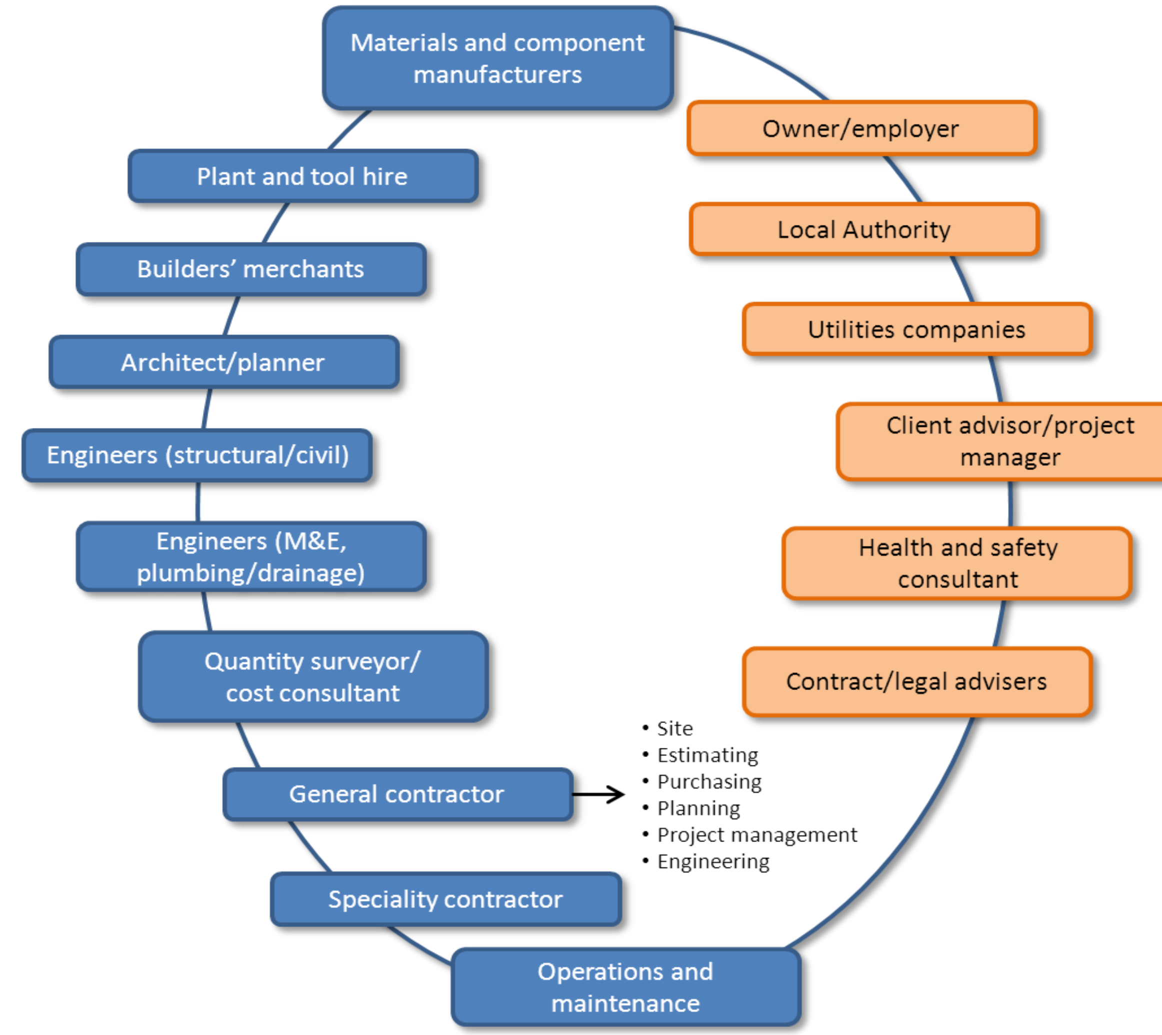
> *"Information technology (IT) has made an impact on construction, but the rate of absorption has been slower than expected."*

> *Data and information must be shared across a large number of participants and, importantly, through the lifecycle of a project, from inception through design, construction and use, creating a number of problems*

The importance of IT in the lifecycle

Information technology (IT) has made an impact on construction, but the rate of absorption has been slower than expected. For example, computer-aided-design (CAD) systems have become more powerful and sophisticated over the past ten years, yet some companies still use CAD as a draughting tool rather than as a design tool with the capability for 3D and visualisation.

Despite the emergence of sophisticated computer-based information systems in construction, paper-based forms remain the most common method for recording information on site. Even when keyboard entry is practical, the rate of data entry is low and errors due to mis-keying are high. The `bottleneck' of information flow at source inevitably affects the cost, timeliness and accuracy of these systems, forcing operatives to spend unnecessary periods of time recording information which is secondary to their main task.



In the traditional business a lot of time is spent by IT departments focused on the 'T', with too little time spent on the 'I', the information. Construction projects always have new and temporary teams, they do not have the luxury of a production line that is constantly undergoing improvement. Data and information must be shared across a large number of participants and, importantly, through the lifecycle of a project, from inception through design, construction and use. This creates a number of problems:

- The diversity of parties involved in the process and the long supply chain.
- The temporary nature of the project delivery team.
- The lack of feedback about how products perform through their service and design life.
- The focus on delivery, rather than on the whole life of the project in use.
- The gap between the information on the 'as-built' drawings and the needs of the team who use and operate and maintain the building.

Auto-ID can help to bridge the gaps, it can interface with building information modelling (BIM) in the future, and it can help track materials (traceability) from the order through to installation. Auto-ID is being used across the supply chain already but there is more scope. It does not need one large, all-embracing system, it needs small incremental steps which eventually lead to a major stride forward. Having the right tools to create and interpret data is important, as is visualisation and the man-made interface.

The business case for Auto-ID

Any auto-ID standard must be sufficiently flexible to accommodate potential uses at any stage of the construction cycle. Furthermore, a well-structured system will stimulate adoption in life cycle stages which have hitherto failed to use auto-ID. For example, bar codes are often designed to satisfy a discrete stage of a production cycle.

There are a number of areas where RFID technologies can offer potential benefits to construction businesses:

- Enabling the integration of design, production and operation by improving traceability of materials.
- Reducing losses on site by better security using the RFID tracking abilities.
- Improving maintenance and repair operations with real-time information.
- Improving health and safety on site with readily available information on tags.
- Making environmental and costs savings through the reduction of wastage by better inventory control and tracking, e.g. just-in-time delivery.
- Real-time information for better and more-informed decision making.

If auto-ID is used for say, the fabrication, shipping, tracking and storage activities in the supply chain for building materials, several parties are involved, each bearing a cost for setting up the auto-ID system. Demiralp et al. (2012) investigated the savings in moving from a manual materials tracking system to one using RFID. Their results showed that high productivity gains could be made e.g. 93% in the identifying and locating processes of the company investigated. The cost savings of the sample companies was about 3% of the project cost with 65% of the saving due to reducing the level of missing materials. The manufacturer, rather than the contractor, benefited most from the savings at a ratio of 0.62 to 0.38 (Demiralp et al. 2012, p. 129)

There are deficiencies in terms of consistency and adequacy in the creation and transfer of the vast amounts of information generated through a facility's lifecycle. Problems arise from the lack of information capture or loss of information itself when moving across different organisations, teams, and stages through facility lifecycle. These losses can be grouped under three major headings spanning the following lifecycle phases:

- Loss of design-related information
- Loss of construction/production-related information
- Loss of O&M related information

Case study - The Consolidated Contractors Company (CCC)

(CCC is based in Greece - with over 110,000 employees from over 90 different nationalities and revenues of US$4.2 billion in 2012 www.ccc.gr/home.php.)

The problem

Monitoring/controlling access at construction sites and camp gates is becoming more time-consuming. The current procedure involves security personnel checking each labourer manually by comparing an ID badge against a list. This can mean a 1 to 2 hour wait for the labourers at the site gate.

The solution

- *Two solar powered RFID-Active Readers were installed at each of 6 gates to control and record the "in & out" access of employees to the construction site. Each device had an electrical power source as a backup plan.*
- *500 key fob active tags were distributed (to all employees).*
- *A speed hump, placed before and after each device, was mandatory to overcome the tag's eight-second transmitting frequency.*

Return on investment

The overall savings estimated based on the RFID-Active Reader's more efficient process for site personnel entering and exiting the site was calculated to be approximately US$6,500/month, assuming five minutes are eliminated from the delay at the gate for 500 employees, averaging US$6.00/hr. per employee, and 26 calendar days worked per month. With the enhanced control the RFID-Active Reader provides for starting and ending employee work hours, an estimated average of 15 minutes per site personnel can be saved. Overall, the new technology saved 20 minutes/day per person - a US$26,000/month saving.

Loss of design-related information

Current design practice has deficiencies in preserving the information regarding the design process. Design outputs (i.e., drawings, renderings, specification documents, bills of quantities) are inadequate in explaining how they were derived. This is because design processes in construction projects are highly dependent on paper- document-based data exchange. Moreover, the resulting design documents, regardless of the transfer medium, only show a finalised design choice. This practice causes co-ordination problems with cost and time implications (Teicholz and Fischer, 1994). The manual transfer of design documentation to other project participants for their interpretation causes breaks and gaps in the design development and building construction process (Garber, 2009). This also means the designers do not receive the valuable feedback regarding issues on the construction and operation of their design choices (Andreu and Oreszczyn, 2004).

> *"There are many opportunities for improving the services by learning from the past experiences, made possible by efficient information collection mechanisms."*

Loss of construction/production related information

Before commencing on site, a contractor must evaluate the design information from the perspective of cost, time, resources, and risk. The bid and construction programme must reflect the interpretation of the design requirements and the relevant codes and standards. During the course of the construction phase, a large amount of information is generated about the ongoing processes (tasks) and the final product in progress. Only some of these are required for the organisation of the immediate work processes; thus, they are temporarily recorded and distributed across stakeholders.

Most of the information is not recorded and so is lost due to its non-critical nature at a given time. Some information may be stored in the memory of a professional (as experience), but this information hardly moves beyond their personal encounters and so rarely gets transferred into solving the design and construction problems across the organisation (Kartam, 1996).

The production team will often change as the project moves from the early stages through the production process. All construction teams are project focused; as a project is nearing completion, much attention is placed upon finding the next project. The priority is continuity of work in a cyclical and market driven industry. This does not lead to a cohesive industry all focused upon client satisfaction in the long term and through life service.

Many efforts have been made to devise ways of capturing the experiences of professionals, i.e., utilising lessons-learned schemes (Carrillo and Chinowsky, 2006). However, these efforts have been undermined due to a number of reasons: unreliable communication channels between experts and less experienced individuals; difficulties in updating huge lessons-learned databases; a lack of meaningful classification systems; difficulties in applying new systems into existing operations, and a concentration of focus on failures and incidents instead of having a balanced catalogue of positive and negative experiences within facilities (Kartam, 1996).

There are also deficiencies in capturing the variations on the original design solution. There may be minor variations in dimensions, material finishes, component brands, or installation methods. If these variations are not captured during construction, their identification (as-built data) in later stages of the facility lifecycle is very difficult and costly. In parallel, most of the times process variations and construction team feedback on the applicability of design are not captured and/or transferred.

Many the large firms use auto-ID technologies,. However, SMEs, despite having mobile technology available (even if it is just a mobile phone), have not made full use of the available technologies. They cite cost and lack of IT knowledge as some of the reasons.

Loss of Operations and maintenance (O&M) related information

The O&M of a facility generates a significant amount of information, which has many potential uses. While some of this information ends up recorded in FM job sheets, invoices, and reports; some does not even get captured. Even though some of the information is recorded, it is simply not useful for future needs due to loss of context and relationships.

During the operation phase of a facility, many activities are required to keep the environment in a habitable state. These are directly influenced by the history of the facility, i.e., the choices and activities accomplished during design, construction, operation, and previous maintenance works. If the operational history of the facility was to be captured in a systematic and coherent manner, improving the future services would be much easier. There are many opportunities for improving the services by learning from the past experiences, made possible by efficient information collection mechanisms.

O&M activities can potentially be recorded in a semantically rich and coherent manner. Real-time data capturing mechanisms during a maintenance activity can generate contextual process information in relation to a specific component, system, or space. Such data, then, can be transferred to designers as a feedback on their earlier choices. However, currently there are neither recording systems, nor organic connections between the operators and the designers for feedback purposes.

Case study - Turner Construction Company
Supply Chain Management: Barcoding & RFID Tracking

Turner uses barcodes and RFID tags to track installation status and product information for equipment and building systems, leveraging new technologies to better track materials, equipment, and labour. For example, scanning the barcode or RFID tag on a prefabricated door (complete with mounting hardware) lets the Turner team know what type of door it is, and verify where it is to be installed. Turner also uses RFID tags on workers' hardhats to track manpower on site to improve safety and the productivity of manpower tracking.

Uses of Auto-ID in construction

Auto-ID and safety

Site safety is a key issue in modern construction project management. RFID has been used successfully in site safety; it is a tool for detecting human error. When errors occur, a mobile short message can be sent, warning employees to pay attention and to correct the error immediately (Chao et al, 2007). An RFID-enabled safety precaution system could inform workers of potential risks on site by using ubiquitous RFID. In this case, a construction site will be divided into different zones, with each having a different colour (e.g. red, green, and amber) to indicate the potential dangers. All the potential risks such as fire, electrical, and chemical hazards can be registered on RFID tags that are ubiquitous on site. An embedded tag can alert the site worker to hazards, both static and moving. By linking the tags with an RFID reader and an alarming system, it is possible to give workers instructions and precautions to take for the potential risks. RFID has the advantage of providing real-time visible and traceable information on site. Using a tag in the workers' helmet, a personal warning can be emitted, loud enough to hear despite any site noise. The technology can 'see' around corners and through obstructions. Another application is a tag attached to plant and machinery that can detect use by an untrained/unauthorised person and send a warning.

Source: http://www.rfidjournal.com/articles/view?10471

The risks of RFID identified by CCC*

A variety of risks are associated with the use of a fixed RFID-active Reader to manage site access security. CCC's aim was to reduce the waiting time for security checks at the site entrance, provide attendance data and have real-time information about the numbers of personnel on the site. The identified risks were:

- *The cost of the RFID-Active solution is high compared to all other solutions.*
- *Rules and regulations of active tag frequencies vary in different countries.*
- *The long-term cost of replacing the active tag's battery (life time=one year only).*
- *The design of the active tags in key fob form and the ability to replace the battery.*
- *The accuracy of the readings and the tag's eight-second transmission frequency.*
- *The availability of the reader in local markets.*
- *The remote location of the project (300 km from Dubai).*

The project was in the Habshan Area, 150kms from Abu Dhabu and 300kms from Dubai. The site was in harsh desert with high temperatures and levels of humidity.

** CCC is based in Greece and is predominately a construction company, providing project management, engineering, procurement & construction services for: oil & gas, petrochemical, pipelines, building, heavy civil, marine, and maintenance works.*

The company employs over 130,000 people and was ranked 21st in ENR's Top 250 International Contractors in 2013.

Auto-ID and site management/security

Construction sites have specific needs for access control; an effective access control system can keep the site, staff, and assets secure. If this is combined with an attendance checking system, it can provide a time and attendance record as a basis for further uses such as allocating work, calculating wages, and so on. Current access control and labour attendance checks, undertaken manually by punching in and out of timecards, have many drawbacks. RFIDs allow the tracking of materials, components and plant and machinery. This helps in the management of the site but could also be used in site security. Swipe cards using auto-ID technologies can ensure entrance to a site is managed and, in restricted areas, only authorised personnel could be allowed in.

Each worker will have a RFID card which could be integrated with an existing card (e.g. railway card) to record their IDs, photos, access authorities, and companies, when there is more than one subcontractor. A reader at the entrance/exit of the construction site will retrieve the information, match it, and give or deny access. The system will record the entering and exiting times automatically and this information will be used for calculating wages via a computer system.

Auto-ID and tracking of machines and tools

Construction machinery ranges from large-scale machines such as cranes and excavators to smaller tools such as pneumatic breakers, welding machines, and wrenches. Managing machines and tools efficiently is not only about managing them as assets but also to ensure the smooth running of scheduled construction works. The real-time visibility and traceability of machinery becomes more important when the construction site is large (e.g. a civil engineering project) and the placement of machines and tools becomes more critical. Domdouzis et al. (2007) described the benefits of tracking equipment in the maintenance of oil facilities. Tracking of machinery is equally important as the tracking of workers. Whilst people can be tracked by speaking to them using a walkie-talkie or a mobile phone, it is more difficult to track machinery, which is where RFID technology can be of use. RFID tags can store the log of borrowing and returning thus helping to track the machines and tools, preventing loss, misplacement, or burglary.

An unmanned, fully automated cabin which provides instant access to a range of tools and other equipment. Access is gained using a swipe card, with each item is electronically tagged using RFID.

Source: http://www.aplant.com/athu/

Auto-ID and materials management

In a typical material supply chain, construction materials ordered are shipped or transported by trucks from factory to material distributors, and then to an on-site warehouse/storage area. Material information such as manufacturer, quantity, specifications, etc. should be readily available to decision makers such as buyers in the head office, project managers on site, and truck drivers on the road. Tagging materials and components at source could allow tracking during and after delivery to site, providing real-time information. Real-time information is more important when a Just-In-Time (JIT) method is adopted to deal with compacted jobsites commonly seen in congested urban areas. In these cases, real-time information visibility and traceability is highly desired and RFID technology can be implemented for this purpose. Information can be collected electronically (through a handheld or static (overhead) reader) on delivery, which means less paperwork and less input errors.

Information about the materials, such as their specification, source, fitting instructions, maintenance data, storage requirements, safety information and so on is stored in RFID tags stuck to the materials. Similar to Wal-Mart's practice to tag its food and drink, this has been seen in construction as useful in tagging large construction components.

Case study - Skanska USA

Skanska USA combined RFID tags with Building Information Modelling (BIM) on their open-air stadium project in Meadowlands, New Jersey.

The company tagged nearly 3,000 pre-cast concrete pieces that formed the seating bowl, and improved the supply chain of the project. As the pieces move through the four phases of the production process, RFID information is fed into Tekla Structures, a BIM solution from Tekla Corporation that covers the entire structural design process from conceptual design to detailing, fabrication, and construction. With this combination.

Skanska was able to gain a view of the supply chain and visualize the status of each piece of the project in the BIM system with up-to-date information from the field. The new Meadowlands Stadium was the first project in the USA to combine field software, tablet PCs, RFID, and BIM for integrated production management.

Estimates show that this approach will accelerate the schedule by 10 days, which means US$1 million in savings. This is achieved by more accurate and up-to-date production information, which includes:

- *What materials have been fabricated;*
- *Whether materials have passed quality assurance;*
- *When materials have arrived on the jobsite; and*
- *Which materials have been incorporated into the structure.*

Integrated tagging across the life cycle

Tags permanently attached to components at the manufacturing stage would be beneficial to all stakeholders in the value chain. Information could be updated with accumulated lifecycle information, providing an integrated information system. What is more encouraging is that today's material manufacturers are open to RFID technology for tagging their products. Locations of materials can be efficiently tracked by combining it with Global Positioning System (GPS) and Geographic Information System (GIS) (Lu et al., 2007).

Material inventory management is of particular importance in construction. A proper amount of materials in stock can maintain a healthy cash flow for a contractor. This is particularly true as today's companies tend to purchase materials from a global market. However, storing them in a warehouse or on a construction site is not free. Real-time inventory information can further facilitate another round of materials management processes such as ordering, transporting, stocking, and use. Traditionally, these were done manually by sending paper documents back and forth. RFID technology can be implemented to improve the inventory management of construction materials, allowing information sharing to be conducted electronically and in real time.

Long-range RFID readers could be installed in the storage area to retrieve the material information embedded in the RFID tags attached to the materials. When the newly-arrived materials are placed in the area, the readers read the tags and update the inventory database automatically. When the materials are taken out for use, the system works in reverse with the amount of material being deducted from the database.

Case study FCC and ACCIONA

Spanish construction firms *Fomento de Construcciones y Contratas (FCC) and ACCIONA excavated a pair of railroad tunnels near the city of Vigo (Spain) to expand the North-Northwest Railway Corridor, which connects Madrid to Galicia for the state-owned ADIF rail lines. Inside the tunnels were multiple hazards, including heavy equipment, dim lighting and periodic blasting to bore through the rock.*

To track the hundreds of workers located within these tunnels, 24 hours a day, the companies wanted technology that would enable them to know the locations of workers and wanted employees to be able to send a distress message if they were in trouble.

The two companies used the construction site's existing infrastructure, with Wi-Fi nodes connected with fibre optic cabling for data and voice transmissions that would allow them to use a real-time location system (RTLS). Each employee was issued with an Ekahau T301BD Wi-Fi-enabled RFID badge, which transmits at the Wi-Fi 802.11 protocol in the 2.4 GHz frequency band. This allowed two-way communication (with texts) and for a distress alert to be sent.

Each badge had a unique ID number but this and the employee's identity were not matched electronically, allowing anonymous tracking. Managers could view a map of the tunnel on their computer displays, containing icons representing all staff members who were wearing tags.

Auto-ID and off-site manufacturing

Prefabricated construction allows:

- More controlled conditions for weather, quality control, improved supervision of labour, easier access to tools, and fewer material deliveries (CII, 2002).
- Fewer job-site environmental impacts because of reductions in material waste, air and water pollution, dust and noise, and overall energy costs. However, it may also entail higher transportation costs and energy costs at offsite locations;
- Compressed project schedules that result from changing the sequencing of work flow (e.g., allowing for the assembly of components offsite while foundations are being poured on-site; or allowing offsite assembly of components while permits are being processed);
- Fewer conflicts in work-crew scheduling and better sequencing of craftpersons;
- Reduced requirements for on-site materials storage, and fewer losses or misplacement of materials; and
- Increased worker safety through reduced exposures to inclement weather, temperature extremes, and ongoing or hazardous operations; better working conditions (e.g., components traditionally constructed on-site at heights or in confined spaces can be fabricated offsite and then hoisted into place using cranes).

General requirements of a material tracking system (Sardroud, 2012)

- **Safety**: Technology must work at any location and time and not harm people.
- **Cost**: It must have reasonable set-up cost. For instance, GPS can provide positional accuracy, but tagging hundreds of items with simple but expensive GPS receivers would not be reasonably practical. Running costs should be minimal, and, in this manner, reusing tags will help the system to keep minimum variable inventory.
- **Accuracy**: Technology-aided tracking and locating processes should result in more accurate locations than those from manual localisation practices. For example, RFID technology is suitable for identification purposes in tracking individual items, but its current applications do not provide sufficient location accuracy without relying on a fixed communications network.
- **Network**: Network coverage should be the most suitable for small device communication, capable of scaling to meet the eventual needs of an application. The selection criteria are a mix of coverage, wireless link distance and data bandwidth.
- **Flexibility and scalability**: In order to successfully integrate with other project management systems, this system must be flexible in terms of its implementation, and have minimum infrastructure requirements for setting up the system and transferrable to new projects.
- **Ease of use**: i.e. easy to mobilise, be simple and user friendly in its operations and, simultaneously, reduce errors associated with human roles.
- **Ambient environment**: Technology must work well when natural illumination is low, obstructions are present, and the likelihood of signal multipath is high.
- **Ruggedness**: Such a system must be rugged enough to withstand harsh construction environments, which are inherently exposed to adverse conditions, e.g. dust, rain, mud and snow.
- **Time**: It should take minimal time for initial set up. The effortless data collection processes must require less time for identifying and locating materials and equipment than traditional methods.

BRE research estimated that if the UK off site manufacturers adopted auto-ID technologies it could lead to annual savings of between £10m and £30m (BRE, 2004). Furthermore, the likelihood of improving/digitising delivery records could reduce litigation costs. The same report identified a number of applications for RFID in off-site manufacturing:

- Paperless invoicing and ordering system
- Inventory control
- Stock control
- Project monitoring correlating manpower used with tasks performed
- Project monitoring correlating use of equipment resources with tasks performed
- Manufacturing process control through centralised tracking and resource allocation
- Erection tracking
- Maintenance
- Demolition and disposal (end of product life)
- Dispute Resolution - with the availability of data on late delivery, non availability, etc.

Auto-ID and quality assurance

RFID technology can be used to improve construction quality in a number of ways. For example, it was used by the MTR Corporation in Hong Kong to indicate the depth of piles as there had been instances where piles did not actually penetrate to the designated depth. In this case, RFID tags were planted into the pile ends and their radio signals indicated the depth to which the piles had penetrated.

RFID can also help to combat counterfeit materials. With RFID tags being applied, each material will have a unique serial number from the manufacturer, similar to the RFID tags in library books. Project managers can double-check the materials to ensure the materials used are provided by a qualified supplier and are used appropriately.

By implanting RFID tags into concrete blocks, it can facilitate the quality test, for example, to indicate the concrete testing samples. The advantage of using RFID tags over the use of paper labels is that the former are set into the concrete and are irremovable unless the concrete itself is destroyed. Therefore, it prevents the concrete blocks from unintentionally being replaced.

It is generally agreed that the benefits of using prefabrication include: reductions in cost, time, defects, health and safety risks, and environmental impact and a consequent increase in predictability, whole-life performance and profitability (e.g. Gibb, 1999; Sparksman et al., 1999; Housing Forum, 2002; Parry et al., 2003; Venables et al., 2004).

A BRE survey on the use of RFID in off-site manufacturing showed that the main driver for the use of tagging and wireless technology was profitability (BRE, 2004). The companies surveyed were looking for at least a saving of 1% on turnover and an ROI of one to two years. It was estimated that savings for an off-site manufacturer could be over 10% because of "an improved inventory, better stock control, and the delivery of the correct product" (BRE, 2004, p. 2).

Auto-ID and the construction supply chain

Construction manufacturers and suppliers represent a key driving force in the development of the use of auto-ID in the construction industry. However, the current level of bar code usage by builders' merchants varies significantly. All the large merchants use bar coding at EPOS (electronic point of sales), using codes originated during manufacture.

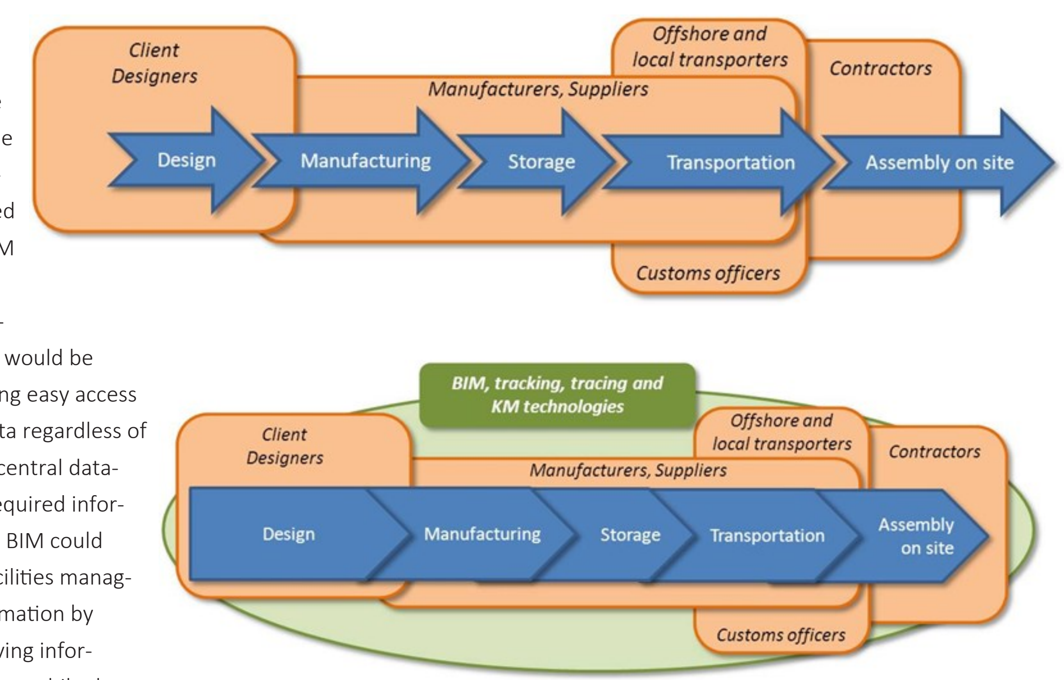
Characteristically, bulk products do not lend themselves to bar code identification. However, off-site prefabricated components/modules provide a realistic opportunity to easily use RFID tags. These could be attached in the factory and used on site - the tags could give assembly instructions and during operation, they could give maintenance and life cycle information.

Auto-ID and BIM

Integrating RFID technologies into BIM, would allow better monitoring of building performance and enable the capture of information about the facility for building maintenance activities (Cong et al., 2010). Structured information could be taken from BIM database and input to RFID tags attached to the components. Essential data related to the components would be readily available on the tags providing easy access for whoever needs to access the data regardless of having real-time connection to the central database or having a local copy of the required information. The integration of RFID and BIM could potentially have two main users: facilities managers and work crews, accessing information by interrogating the RFID tags or receiving information from the main database via a mobile device. The figure on the right shows how BIM can help integrate the process from design to assembly on site.

Auto-ID and buried asset tagging

There is not only a cost in locating buried pipes, cables etc. for maintenance/replacement but also the cost of rupturing/damaging them if they are not located accurately (Dziadak et al., 2005). Technologies that have had some success include: ground probing radar (GPR), acoustic devices and induced currents. However, these are expensive, time-consuming and not always successful in locating non-metallic buried assets (Dziadak, 2008; Domdouzis et al., 2007)). Research and practical applications have shown that RFID tags can be effectively used to locate underground assets but more extensive research/testing is needed. One example is the use of 1,000 RFID-enabled marker balls buried around a new runway at the Hartsfield-Jackson Atlanta International Airport by the US Federal Aviation Administration (FAA). The marker balls allow the FAA, airport employees and contractors to use handheld RFID interrogators to locate utility cables and pipes buried 5 feet underground, determine what type of infrastructure they represent and who owns that infrastructure.



An illustration of a pre and post BIM-integrated construction process

The push and pull factors

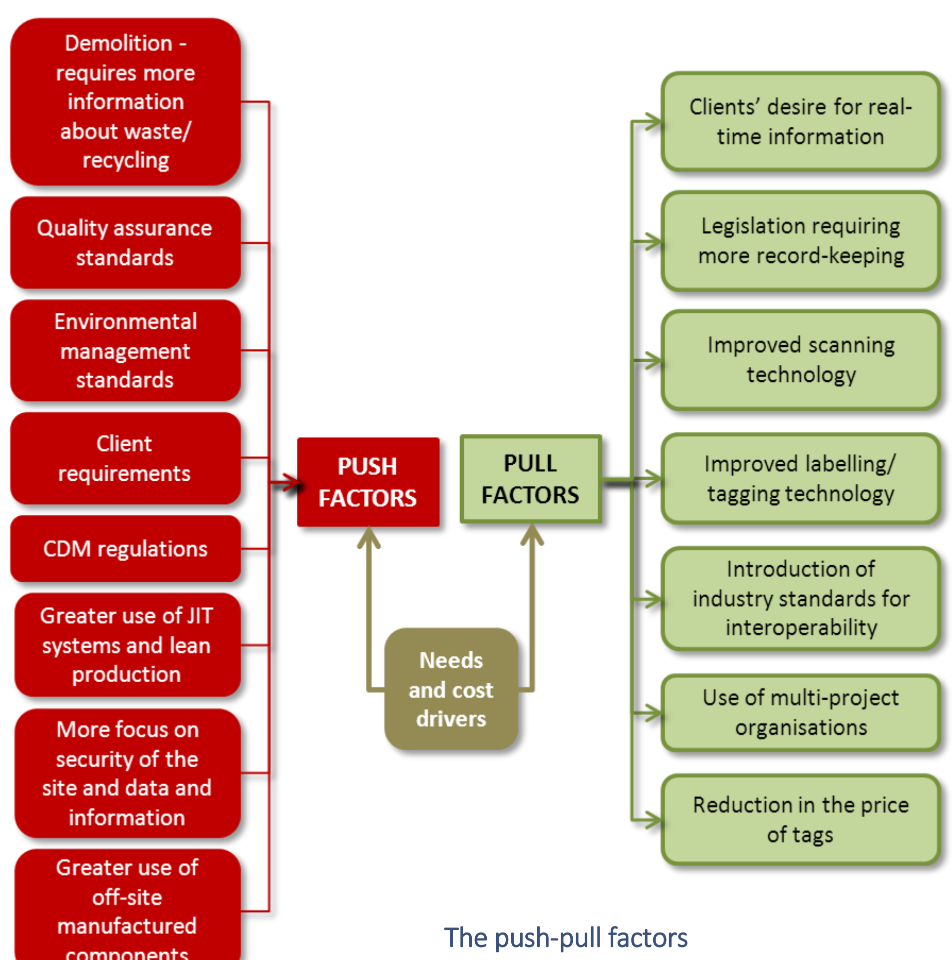
A number of pressures are likely to act as a catalyst to auto-ID usage in construction in the near future. The technological `push' and `pull' factors which will have a significant effect are shown in the figure below.

The type of contract used in a project may have a significant bearing on the attractiveness of an auto-ID solution. In particular, the contract type will determine whether the introduction of auto-ID is client driven or contractor driven.

The increasing use of multi-project organizations based on long-term relationships between contractors and suppliers will greatly improve the benefits of developing open bar coding systems. Instead of competing for individual tenders, suppliers can establish a partnership with contractors and develop an auto-ID solution which offers ongoing advantages.

Legislation is likely to provide a major `push' factor, with an increasing onus on contractors to monitor and track construction site activity. In particular, quality assurance standards (ISO 2000 and BS5750) and environmental management systems standards (BS7750) make particular demands on the amount of recording and data entry.

The UK CDM regulations (construction design and management) also impact on the liability of designers, requiring the provision of documentation for maintenance and operation. Documentation of this nature could easily be accommodated in portable data files and be made available at a local level.



The push-pull factors

Barriers to the use of Auto-ID in construction

The main barrier has been the highly fragmented structure of the construction industry, with no single group being the driving force for the industry. The US giant WalMart and the US Department of Defense are both large enough to create their own industry standards, which have then been used by others.

The failure of the construction industry to widely adopt auto-ID can be explained by a number of factors:

- Failure of clients to enforce the use of auto-ID technology: much of the benefit derived from auto-ID stems from the transfer of reliable information between organizations involved in the construction cycle. Whilst inefficiencies within organizations are exposed by uncompetitive tenders or product prices, the more endemic inefficiencies relating to flows between organizations are often concealed. As a result, the client ends up paying many times over for the re-entry of information which becomes more inaccurate and incomplete at each stage.
- The absence of long-term relationships between organizations involved in the construction process. In industries where bar coding has proven successful such as the automotive industry, a single large manufacturer has been able to dictate the terms for using bar code labels to a large number of much smaller competing suppliers. In construction, there is no long-term relationship with the main contractor. The absence of such a relationship undermines investment in bar coding as there is no guarantee of sustained custom for suppliers. Framework agreements can help to establish a longer-term relationship, but there is always a mentality that frameworks have a finite life.
- A standard coding system needs to be agreed by all organizations involved in the construction process, from design through to maintenance.
- Widespread misunderstanding about the potential applications and benefits of auto-ID.
- The attitude of staff to new technology where there is no immediate benefit: this is particularly true of data-gathering technologies which are seen by the operator as an obstacle in the way of carrying out an operation. With no feedback on the information which is collected, there may be a lack of motivation to make the technology work.
- Concerns about the reliability of an auto-ID system. Technological dependence in a critical process is seen as presenting an unacceptable level of risk exposure.

RFID expertise/research around the world

FINLAND	Access control at construction sites	ELKU, - the Confederation of Finnish Construction Industries RT
	RFID systems to track location	Ekahau Inc. - solution provider
	Jobsite logistics - mobile RFID interaction with BIM	Nokia and TeliaSonera - solution provider
DENMARK	Embedded RFID in concrete - intelligent concrete	Dalton Betonelementer A/S - construction supplier and Cadesign - solution provider
	Online registration of quality data on construction site - embedded RFID in fx. Concrete	E TJEK ApS. - solution provider
	RFID embedded in doors for production management	Vest-Wood Group - construction supplier
SWEDEN	Asset management, access control at construction site	Safetool AB - solution provider
	Access and gate control at construction site	TracTechnology AB - solution provider at SKANSKA site
	RFID embedded in doors for production management	Swedoor, Vest-Wood Group - construction supplier
UK	Electronic tagging of materials and components - iTAG	Bovis Lend Lease Ltd.- contractor
	Data tagging for maintenance of plant	Bovis Lend Lease Ltd. - contractor - Calderdale Hospital
	Rental equipment delivery performance through RFID	Armela Systems for AMEC group
	RFID tag leaks bolt tensioning - RFID to identify pipe-work joints	Hydra-Tight with Intellident, a British Information Systems company
	Path-finding RFID asset tracking	BT Auto-ID Services at Laing O'Rourke construction site
	Service scheduling using RFID	Byzak Contractors Ltd.
USA	RFID tacking of trucks at construction sites - provider of bulk rock and asphalt for construction	The Granite Rock Co., USA - construction supplier
	Tracking of large metal pipes via RFID	Flour Construction - contractor
JAPAN	RFID based nuclear power plant construction - manufacturing and installation with cable connected navigation system	Hitachi - service provider
	RFID bolts and digital torque wrench	KRD Corporation - solution provider
	Logistics operations using RFID to reduce CO2	Consortium led by Waseda University
HONG KONG	Testing procedures in concrete improved by RFID	MTR Corporation (MTRC), Government developer
	Major prefabrication components (e.g. façade, volumetric kitchens) in building projects are tagged with RFID for quality assurance, with a potential for cross-border logistics and transportation management.	Hong Kong Housing Authority (HKHA), MTRC, and some private developers
	Prefabrication components for the Venetian Macao hotel and casino resort were manufactured in Shenzhen and shipped to Macao. RFID tags were applied for facilitating shipping and assembly.	Yau Lee Group –Manufacturer and contractor
	All trees under HKHA's management are attached with RFID for tracking its health	HKHA – government developer
	Slopes in Hong Kong are tagged with RFID for better monitoring and maintenance	Civil Engineering and Development Department, Hong Kong
CANADA	Tracking of power tools	Construction
GERMANY	Tool tracker - Bosch's safe and sound tracking system	Bosch Group

The big questions

Who pays for auto-ID technology?

A proven success in the use of RFID is in materials and asset management. Costs are involved in both the front end – the tag - and the back end – a manufacturer/supplier's computer system or the contractor's database. So the big question is: should the supplier/manufacturer absorb the cost of tagging items and maintaining a database (which is what most large suppliers do), without passing the cost on to the customer/contractor, or should the contractor have their own tagging system which will be consistent across all their projects?

It may be argued that tagging goods/materials by the supplier could give them a competitive advantage and they could spread the cost of doing this across their whole stock. If the contractor uses their own tagging system, this would cover goods/materials not automatically tagged by a supplier and would maintain an element of control. In the retail industry, for example, Walmart took it upon themselves to introduce an RFID-based system, insisting that all their suppliers conform to Walmart's protocol. The size and the buying power of such a retail giant was clearly an issue here. The tags, labels and readers are provided by a wide range of suppliers; but the costs involved are not just in this equipment but also the maintenance of the database, and collection and curation of the data.

What are the major technology issues?

RFID systems need to be customised according to its application. Consideration needs to be given to the types of material to be tagged and, particularly important for construction, the ability of the tags to withstand harsh conditions. When working overseas it is important that tags and readers operate in the radio spectrum band licensed by the host country's regulations.

Interoperability of the technology between a firm's RFID system and that of its supply chain is another issue. An entire RFID infrastructure needs to be established if integration is to be achieved (Ornauer et al., 2004).The fragmentation of the construction supply chain makes the integration of an RFID system across all suppliers a challenge. In the retail industry this has been overcome by industry standards and the pressure on suppliers by large companies. Framework agreements, partnering and trans-project collaboration could reduce the number of suppliers, which would allow for greater integration. However, construction companies have been successful in using RFID – see the CCC and the Skanska case studies.

Cost reduction or value creation?

The introduction of RFID can bring many savings, such as reducing labour costs, minimising wastage/loss/misplacement of materials and general efficiency improvements. The other side of the same coin is value creation. This comes from the aforementioned savings which increase the ability to improve performance to meet time and cost targets. Real-time information can help to create value, while integrating the supply chain with RFID-enabled logistics can also enhance the value creation chain.

Are intellectual property rights an issue?

Interoperability and the sharing of databases raises the question of how intellectual property rights (IPR) can be protected, particularly as data are not costless to collect. The European study by CE RFID (Co-ordinating European Efforts for promoting the European RFIC value chain) pointed out that “an adequate legal framework is required in order to allow business innovations and to ensure people’s acceptance [of RFID]” (CE RFID, 2008). The study explained that the issue of IPR is no different for RFID and the same “arguments” and “protection” apply as in other technological fields. The privacy issues of tracking and tracing people using RFID is the same for CCTV cameras, which are already used on many large sites.

Where is the best place to start?

Do not be over-ambitious. Auto-ID is an established technology, it can help to make a business more efficient, it can help to manage data and information effectively. Start with basic tasks and expand towards integrating systems and information.

The retail and health industries present an ideal blueprint for the implementation of bar code standards in construction. Both industries have successfully established a single self-funding body which serves the interests of manufacturers, suppliers and providers (retailers or healthcare providers) alike. Whilst bar code symbology has attracted the most attention in construction research, the focus of attention within the retail and health industries has been on article numbering and data structures to enable open systems. In this connection, developments in bar coding standards need to be consistent with construction standards in electronic data interchange (EDI).

The introduction of global agreements with materials suppliers and the formulation of multi-project organizations will greatly increase the appeal of an auto-ID solution. In the absence of a construction industry standard, such organizations may choose to formulate a semi-open auto-ID system which will enable participating organizations to share information in projects. Builder’s merchants and manufacturers already have electronic systems for the ordering and delivery of materials. This needs to be extended or integrated into the construction process.

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