RFID APPLICATIONS IN CONSTRUCTION AND FACILITIES MANAGEMENT

SUBMITTED: January 2006
REVISED: July 2006
PUBLISHED: September 2006 at http://www.itcon.org/2006/50/
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SUMMARY: *Construction is following the general industry trend towards the introduction of hard and soft automation for many aspects of materials identification and tracking. Recent developments in RFID (Radio Frequency IDentification) tagging provide the hardware solution and cyber-agents are part of the software scheme employed. The agents – programs that can make autonomous decisions and take necessary action when required – are totally dependent upon sensors (rather than human intervention) to provide real-time information on parameters such as location, condition and timing: RFID tags are seen as an appropriate sensor type for providing this kind of information. The potential of RFID tagging technology in the construction and management of facilities is assessed in terms of value chains, a number of applications for improving efficiency are reviewed, and others are proposed. Although there is little evidence presently of RFID adoption in the wider construction sector, the paper concludes that a breakthrough will result from applications that emphasise the management of the building or facility, in particular energy consumption.*

KEYWORDS: *facilities management, RFID, tagging, construction process, cyber-agents.*

1. INTRODUCTION

In its 2000 review, the Construction Industry Institute (Lake and Jaselskis, 2000) identified a number of potential application areas for RFID technology in the sector. These included component tracking (giving the example of compressed gas cylinders), inventory management (small tools as the example) and equipment monitoring. Suggested applications for the future include guided control of equipment, tags that can communicate fatigue or excessive stress in concrete and steel members, and concepts for safety management. However, the cost of implementing RFID solutions has remained high and there has been little take-up across the breadth of the construction sector, with these very application areas remaining under development. In the UK, various government-supported projects are looking at uses of RFID in manufacturing, asset tracking and maintenance within the construction sector, especially applications involving handheld computers for use on-site (Bassi, 2004).

Maintenance applications probably hold the trigger needed to launch and propel RFID in construction and facilities management. The technology will remain costly for some time, as take-up across industry generally has been slower than anticipated; the mass-production needed to reduce costs to a level where it no longer is a barrier to adoption has not occurred. Thus, the cost of using RFID for a single process is likely to remain prohibitive and the best way forward will be to consider applications that can benefit from the use of the hardware across several processes. The RFID tags for construction applications could be utilised for management of the completed facility, thereby bringing justification to expenditure on the RFID system and, importantly, adding value to the facility by automating or at least simplifying the facilities management process. Indeed, asset tagging and tracking is cited as one potential application (McAndrew *et al.*, 2005) from which real value could be added to the management of facilities.

Notwithstanding the relatively little take up of RFID technology across the breadth of the construction sector it has, of late, generated considerable interest. The primary objective of this paper is to examine the relevance of RFID to facilities management against the background of this emerging interest in using the technology to improve the construction of buildings. A secondary objective is to explore potential areas of application within facilities management, highlighting changes needed to design and construction practices to accommodate the benefits of RFID technology.

Before examining individual applications, it is instructive to note the broader picture and understand the implications of introducing RFID technology into the construction sector generally. Three broad areas are involved:

1. Value and supply chains in the construction process, including the subsequent management of facilities.
2. RFID technology – its practical implementation and the results produced.
3. Handling the large quantity of data generated by RFID systems and the use of agent technology.

2. THE CONSTRUCTION SECTOR VALUE CHAIN

2.1 Recognising the value chain

The drive towards more efficient construction is well illustrated by examining the value chain, which follows the lifecycle of a building from raw materials through to the management of the completed facility. Construction projects today more and more less frequently follow the conventional (i.e. linear) model where completed buildings were handed over to the owner through a 'snagging' process, after which the constructor could simply 'walk away'. Today, it is not uncommon for the constructor to retain a measure of control either as part-owner or as the operator of the asset or facility, as would occur under various integrated procurement routes. In this way, the cost efficiency of the completed facility becomes the constructor's responsibility and so it is as important to manage the facility as if it were the construction phase – perhaps more so.

2.2 Value chain modelling

A company's core competences can be determined by using a value chain model to analyse where cost advantages can be gained in performing activities. Value chain modelling (Porter, 1985) separates the business system into a series of value-generating activities subdivided into primary and support activities. The model is generic to most business activities, where relevant construction sector activities are shown italicised in the summary Fig. 1 below.

Primary activities (general)	**Primary activities (construction)**	**Support activities**
Inbound logistics	*Materials and building products supply*	Firm's infrastructure HR management
Operations	*The construction process*	Technology development and procurement
Outbound logistics	*Handover*	Commissioning
Marketing and sales	*Marketing and sales*	
Service	*Facilities management*	

FIG. 1: Value chain activities

All activities need to be performed efficiently, providing quality and best value for money to the customer. Porter's definition of operational effectiveness is about performing similar activities to one's rivals, but performing them better. Several techniques have been developed for companies to gain cost advantage, such as reconfiguring the value chain, linking activities etc., but these and other 'best practice' concepts diffuse rapidly thereby weakening their impact. The major remaining influence in gaining cost advantage is likely to be the effective use of technology, applied systematically across the whole value chain. There are many examples, but the most effective are those that embrace all, or at least several, activities in the chain, and it is here that RFID is seen to have a significant role.

2.3 Optimising the facilities management value chain

As noted, RFID technology has yet to reduce in cost to the point where it is no longer a barrier to adoption. In the meantime, it is becoming increasing clear that cost-effective applications will be those that use the technology throughout the whole service life of the building and not just during construction. Thus, the requirements for optimisation of facilities management – asset management and services – need to be aligned with those of the construction phase. In both the construction and facilities management phases, more value can be realised through a strategic partnership between the organisations involved, and it is generally accepted that such alliances work best when the number of suppliers is reduced to a select few. In facilities management, the extreme case of a single supplier can, in theory, appear to be the most effective solution. In practice, however, a single supplier or very small group of suppliers can be difficult to arrange, especially when considering the whole building life cycle of design, build and operate. A larger group of suppliers can function efficiently, but this brings a high dependency on the compatibility of practices and especially of data and communication exchange formats. There need to be technical solutions for data exchange, communications, inventory specification etc. that are free from problems of standards and obsolescence. RFID is well placed to provide solutions for inventory control and location that conform to recognised data exchange standards and will provide efficient links with multiple suppliers. Even so, open source software is more likely to trigger adoption than proprietary software where licensing costs are likely to maintain artificially high end-user prices.

2.4 Standards

Regrettably, the essential international standards for RFID devices are evolving much more slowly than the devices themselves, and until standards like EPC (see 3.4 below) are widely adopted it will not be possible to reap the benefits of organised supply chains where partners can track each others products as they pass through the chain and across international borders. This is a general, practical problem that is proving difficult to resolve with the integration of most sensor systems for intelligent buildings (Manolescue, 2003); that of connecting the devices together, devising a language they can all speak and then adding intelligence. Moves in the building services industry to consolidate the various incompatible communication and command protocols currently in use are now taking place, moving towards a single IP based framework for building automation. However, progress is rather slow.

Software development at a higher level is forcing the evolution of essential international standards and these will come from major software houses competing for the lucrative supply chain management software market (Collins, 2004). Supply chain management (SCM), the practice of coordinating the flow of goods, services, information and finances as they move from raw materials to parts supplier to manufacturer to wholesaler to retailer to consumer, is nowadays highly dependent upon soft automation. In general manufacturing, these processes include order generation, order taking, information feedback and the efficient and timely delivery of goods and services. In construction, they include project definition, design, procurement of contractors and suppliers, advance manufacture of major components and systems, and product certification along the supply chain.

Supply chain management looks across the entire supply chain, rather than just at the next entity or level and aims to increase transparency and alignment of the supply chain’s coordination and configuration, regardless of functional or corporate boundaries (Cooper and Ellram, 1993). Software for SCM is required to optimise performance of the chain and to embrace agility, flexibility and lean production ideals. An important characteristic of construction is the presence of small enterprises in the supply chain; their ‘membership’ is enabled by ICT/internet solutions that were previously too complex or expensive for them to implement. Consequently, main contractors have become more reliant on other actors in the supply chain than previously (Vrijhoef and Koskela, 1999).

Two important factors have therefore revealed themselves for the successful application of RFID in the construction sector.

1. The cost of the technology will be better justified when its use is spread across more than a single process. It is the final stage in the supply chain, use or consumption, the facilities management process, where significant benefits to the client could be produced by the use of IT (including RFID and similar methods).
2. RFID technology must conform to standards across industry and the sector, in order that multiple suppliers, especially small enterprises, can participate in the project partnership.

2.5 Connections between materials’ and information sub-processes

The interacting nature of materials and information processes in construction are examined by Björk (2002) using process modelling methods. He shows how both types of activity utilise resources which are consumed in the processes (materials, energy, labour, wear and depreciation of machinery) and introduces information as a special type of resource that is not consumed in the process of using it, but nevertheless has a cost and also a value. During construction, the information and materials' sub-processes are integrated by information flows in two directions; in a longer perspective the information process also needs feedback on the performance of buildings during the facilities management phase. In one direction, information needs to be transformed into actions carried out by persons or by persons aided by tools and machines, and in the other, physical impulses such as temperatures, pressure etc. need to be transformed into information using measurement equipment.

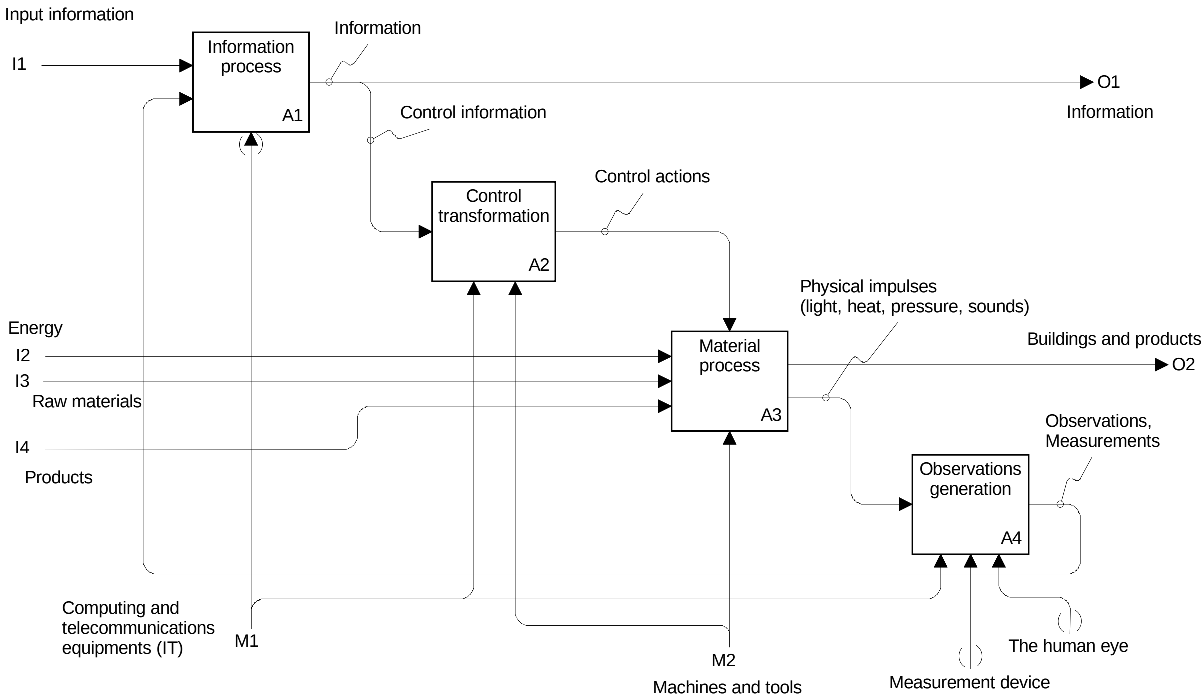

FIG. 2: Process model showing the materials' and information sub-processes (Björk, 2002)

This mechanism can today in many cases be substituted by IT-enabled techniques such as bar coding and automatic pattern recognition. Björk's process model, including control interface activities, is shown in figure 2 above.

RFID is a more robust technology than bar coding for construction applications and is able to provide not only the bond between information and materials, but also provides output in electronic form that is immediately usable for unique identification or as a hyperlink to a database. Yagi *et al.* (2005) propose a 'parts and packets unified architecture' where data/information related to a product is carried by the product itself using RFID tagging. They describe a scenario where the dynamic flow of the parts and packets binds the two networks (materials and information) across the entire business model. Tags will not themselves carry detailed information; they will contain pointers to unique addresses (URL) within a database or specific pages within a supplier's website.

One objective of Yagi's method, which is called 'Product URL-attached parts-oriented-construction' is to achieve higher construction quality by minimising the effects of workers' interpretive skills. Remote servers will deliver precise and relevant procedures to individuals working on-site. As tagged parts move around the construction site, a complementary system of cyber-agents will be required to handle the substantial information flows. The concept is on trial with three major Japanese construction companies as part of an IMS project named IF7II. Notable from the viewpoint of facilities management provision is the idea that virtually all products incorporated in the completed facility will have an attached RFID device that can provide full information (via its URL) for servicing, replacement etc. This extends beyond the obvious plant and equipment, e.g. HVAC and elevators/lifts, to detailed 'fit-out' components, such as light fittings and even colour schemes for painted walls.

3. RFID TECHNOLOGY

3.1 Generally

The RFID market is already a multi-million dollar industry and the potential applications of smart chip technologies are almost limitless. The transportation, agriculture and manufacturing industries have been utilising radio frequency technology effectively for several years in applications such as toll collection, cattle tracking and automobile manufacture respectively. Today, retail industries believe they can reduce costs and increase revenues with better supply chain management, and as tag prices fall with increased production volume the technology is expected to find wider application. RFID tags and their associated data can thus be seen in terms of triggering events and this is where the bulk of the return on investment is likely to be generated (Walker *et al.*, 2003).

3.2 Tag types

Read-only tags are generally used for simple identification purposes, and derive their power from RF energy received (induced) from the reader; they can store only a limited amount of information that cannot be altered. These passive tags are the simplest form of RFID, but nevertheless have far greater capacity than bar code labels for storing information. Whilst universal product code (UPC) labels on typical retail packaging allow only 12 to 14 bits of information, current-generation RFID tags can typically accommodate up to 96 bits. Since bar code labels are only capable of identifying that the item is, for example, a particular specification of door frame, RFID tags could identify exactly which one of the batch it was together with its production history.

The simple read-only tag is not however limited to 96 bits. The unique product identifier can be hyperlinked to unlimited additional information, such as manufacturing batch and production history, product handling instructions, storage or delivery instructions, expiration dates and other details.

Read-write tags generally require battery power (i.e. they are active tags), which limits their operational life, but they can support large memory arrays (32 MB is possible) that can be changed/updated to accumulate the history of a product as it undergoes manufacture and then is put into service.

Sensor coupled tags are a recent development, allowing a sensor measured value to be transmitted to the reader in place of the tag’s stored memory contents. Temperature sensors, for example, allow scanning of large batches of frozen food packages to ensure that none have defrosted. An important application in construction uses similar sensors buried in freshly poured concrete to capture in-situ temperatures, thus allowing concrete maturity to be tracked. A hand-held reader allows reliable records of the curing process to be logged without the necessity of cables (CMMS, 2005).

3.3 Work environment – ruggedness and reliability

One of the most important differentiators between bar coding and RFID tagging is the ruggedness and environmental performance of the electronic tags. RFID tags can operate effectively in temperatures ranging from -40 to 200 degrees C and can perform under rugged conditions or even when dirty.

Although radio frequency devices do not require line-of-sight and can transmit through almost any material, metals may cause signal attenuation. As metal is a familiar material on construction sites, such signal degradation could constitute a limitation (Furlani and Stone, 1999). The RFID tag’s orientation and fixture methods may have to be altered so that the tag can be clearly identified. New RFID technologies claim to align the tag’s antenna and a non-insulated metal material in such a way that the metal actually amplifies the signal of the RFID tag.

The manufacturing process for RFID devices has been developed further in order to produce tags as flexible printed circuits, increasing their ruggedness and reliability for many applications. The flexible circuits can be produced on reels as ‘smart labels’ complete with adhesive backing.

3.4 Ranges, frequencies, capacities and standards

There currently is no defined industry standard for wavelength, but many applications use wavelengths of 125 kHz and 13.56 MHz. The most commonly used tags are low frequency, because they are more easily readable through materials and are not as orientation sensitive as higher frequency tags. The latter have greater read ranges and are less sensitive to noise, but they tend to be more line-of-sight dependent, orientation sensitive and require more power (Liard, 2003).

Tag readers today can simultaneously read 100 to 2,000 tags per second. Active tags can be written to and read up to 100 metres in free air (Collins, 2002). Passive tags on the other hand have a read range limitation of about 2m.

Cross-industry standards for a supply chain strategy based on automatic identification (Auto-ID) are being developed, and this was realised in the 2005 release of Electronic Product Code (EPC) Network specifications. Four standards will eventually be in place:

1. EPC will be stored in the RFID tags, allowing individual products to be identified, counted and tracked in an automated, cost-effective fashion. An RFID reader emits radio waves that alert the tags to broadcast their individual EPCs. These RFID technology standards will take full advantage of the internet and will be open standards, integrated into existing network and software infrastructures. The EPC standard uses a 96 bit data string, typically organised as in the following sequence:

HEADER bits	(8 bits)	Determines structure of following bit sequence.
DOMAIN Manager	(28)	Company/entity responsible
Object CLASS	(24)	Identifies object class
SERIAL ID number	(36)	Unique object identifier

2. The reader is connected to a computer system running the second software standard, Savant, based on Java technology. Savant takes information from the EPCs and enables companies to read or interpret the data so it can be passed along the IT infrastructure to databases or existing back-end or legacy systems.
3. The system then sends a query over the internet to an object name service (ONS) database – the third standard under development – which translates a URL into an IP address, i.e. a web pointer to the page for the product or component. These data are available to, and can be augmented by, Savant systems.
4. Another server uses the fourth standard, Physical Markup Language (PML), to deliver and present comprehensive data about manufacturers' products. Since it knows the location of the reader that sent the query, the system now also knows which plant produced the product.

4. EXAMPLES OF APPLICATIONS FOR RFID IN FACILITIES MANAGEMENT

4.1 Predicted applications

As described in the introduction, technology is recognised as an increasingly integral component of value creation. Rogers (1999) finds that this trend is shaping the role of facilities management value chains and gives, as example, the use of EDI (electronic data interchange), using the internet as a communication medium, which has reduced administration costs and increased flow performance. This example has expanded the following online activities:

1. work management tracking of progress and response to reactive repair or complaint activities;
2. invoice billing, tracking and approval sign-off; and
3. asset management maintenance tracking using plant and equipment identifiers.

As RFID becomes implemented widely in products, the extended use of tags in virtually all aspects of facilities management can be envisaged – from security, maintenance of building services equipment through to cleaning. Just as with the EDI example above, RFID will find application in many areas of the value chain. A number of examples are given below of applications under development that could utilise RFID (and related technical concepts) for effective and automated management of facilities.

4.2 Security – control of access to facilities

Management of facilities requiring control of access may use RFID tags attached to employees' ID badges; this method is already in use in hotels and commercially sensitive sites to permit/control staff access to specific areas. An EU project, OPTAG, is developing this concept to track the movement of checked-in passengers through airports. It is estimated that passengers and their baggage cause some 10% of delays at European airports and this figure is likely to grow as security tightens, and as passenger numbers and aircraft sizes increase. This system will be able to locate to within 1.0m those passengers carrying an RFID device issued at check-in; those who do not turn up at the gate on time can then be found quickly. Active tags will be used, transmitting two short-burst signals every second; the tags, which will be recycled, could be mass-produced for about US$1 each.

The OPTAG project combines the RFID location system with tracking cameras enabling, for example, the identification of lost children. A full demonstrator is being built for trials at Hungary's Debrecen Airport later this year, and Airbus is considering the system for efficient loading of its A380 aircraft (Hibbert, 2006).

Airports are not the only facilities that could benefit from such a system once developed; the concept will find management applications in many facilities, including hospitals, public administration buildings, galleries and museums.

4.3 Inventory

Control of inventory is one of the widest application areas of RFID technology, and is used for applications ranging from hand-tool logging on construction sites to retail stock monitoring in retail stores. This latter use, known as 'smart shelve' is being developed by the Auto-ID Centre at Massachusetts Institute of Technology and is briefly described below. Some of the methods are likely to find future application in facilities management (Auto-ID Labs, 2004)

Companies like Gillette, Wal-Mart and Proctor & Gamble are ordering RFID tags by the million in order to tag every pallet and carton coming out of their distribution centres to reduce losses from out-of-stock, stolen or lost products. Furthermore, the companies expect that with increased tracking ability they will raise revenues by leveraging inventory information into smarter marketing to retailers. The same tags will then be used further down the supply chain with 'smart shelve' software. According to IBM, the 'smart tag – smart shelf' combination would shrink inventories by 5-25%, increasing the efficiency of inventory management. The smart shelves would also be able to communicate the number of products left on shelves and send a message to in-store personnel when the shelves need restocking. The smart shelves also act as security devices, detecting and alerting store personnel when a large number of products leave a shelf at the same time.

4.4 Construction site delivery logistics and materials tracking

Future materials tracking management systems may be able to provide site owners with the ability to determine construction progress and materials delivered by simply walking around a site where all materials are identified and tagged using an RFID system. This would guarantee more accurate estimates of the number and quantity of delivered goods and enable reliable monitoring of 'percentage construction complete'.

An early example of materials tracking was developed in the EU project, *FutureHome* (Wing and Atkin, 2002), as a logistics delivery agent system for use at site gates. The project demonstrated the use of cyber-agents in combination with e-tags performing as an automated site information management system. The cyber-agent supports information gathering of the material delivery process and is able to make decisions for planning and control of the construction process. The system is seen to show the way to several improvements.

1. Reduction of costs incurred from wastage of materials, theft and check-in waiting times for material.
2. Agent technology will enhance communications by informing the driver immediately where the material is to be placed. The agent will confirm delivery of the material with the supplier via the internet and the supplier's website or e-mail address as soon as the material is sent through the delivery gate. The site engineer will be informed as soon as material has arrived on site and can respond and issue further instructions if necessary. If there are any discrepancies, the driver will be informed as will the supplier. The key point to note is that this communication will be immediate, so any problems can be resolved as soon as they become apparent.
3. Time savings will result due to efficient document management. There should be less paperwork, no invoices for the delivery personnel to complete, as all will be automated by the agent. Information will be in electronic form and include instructions for the vehicle driver to follow. Multiple handling of documents will be significantly reduced.

4.5 Document tracking

RFID technology can be used for rapid document tracking, essential in the construction phase to identify the latest version of files and drawings, and also in the facilities management phase to locate original build specifications and layouts. Each document is tagged with an adhesive smart label (RFID printed circuit) that contains a unique ID together with human readable information. The file description is entered into a database along with its tracking number and can be assigned certain parameters like expiration date, permitted movement and personnel authorised to see it. Over time, the database could build up an audit trail of the handling and workflow history of each document file (Texas Instruments, 2004).

4.6 Product life cycle tracking

Manufactured components of all kinds are already using RFID tags for tracking their progress through production and delivery processes. The same tags should be suitable for continued use during the life cycle of the component. A useful illustration of this development comes from the Michelin tyre company, which is now providing product lifetime identification for automobile tyres. RFID tags embedded into tyres are being used to identify the manufacturer's name and plant, store the time and date of manufacture, tyre dimension and pressure specifications. Once the tyre is installed on a new vehicle the tyre identification number and the vehicles VIN (vehicle ID number) are downloaded to a computer database enabling manufacturers to make targeted, quick recalls. Michelin has begun testing its tyre transponders, selling RFID tagged tyres for passenger vehicles from the 2005 model year. Michelin found that off-the-shelf read/write RFID transponders embedded within tyres produced read distances of only three inches, so the company developed their own antenna from microchips produced by Fairchild and Phillips (868-915 MHz frequency band) to meet their 24 inch minimum read range requirement (RFID Journal, 2003).

The automotive industry will extend this application to provide vehicle maintenance and service records by means of the RFID tags embedded within tyres. Such information in conjunction with the car's odometer could track the mileage of the vehicle and alert the driver when the tyres need to be rotated. Since the tags are rewritable, international standards would enable the car to have an up-to-date service and maintenance record regardless of the mechanic or station that has provided work.

This application is automotive, but clearly could be applied directly to buildings and facilities for use with virtually any equipment that requires regular servicing, functionality checking and logging, safety inspection and recording etc. The safety application is significant, as automated electronic record keeping can provide regular unbiased records that are virtually tamper-proof. RFID tags containing pertinent safety information, including regular test records, could be attached to safety equipment such as slings, safety harnesses and belts, scaffolding and hardhats. Similarly, containers of hazardous materials can carry their own handling instructions and usage records in an attached read-write tag.

4.7 Location of buried services

Buried pipes and cables can be located using attached RFID tags, so long as the read range is not exceeded. For plastic pipes, a more suitable technology uses magnetic nanoparticles during production of the pipe. It is possible to introduce conductivity into plastics by simply mixing in conductive nanoparticles in the production process. Thus, magnetic nanoparticles can be used to introduce a unique magnetic 'signature' to plastic items, which can then be scanned like barcodes. In the construction field, this would allow simple and accurate location and identification of underground services such as gas and water pipes, communications cables etc. If the magnetic signatures are repeated at regular intervals along the entire length of the pipes and cables, they could be tracked throughout the site.

4.8 RFID – sensor and network combinations

RFID active tags can be interfaced to networked sensing systems to add further capability to the basic read or read/write tag data function. The example was given in 4.2 above of locating persons within an airport. Wireless networks within a facility, a hospital for example, will allow real-time location of vital mobile assets. This provides an ability to find equipment immediately and also improves asset utilization, as well as reducing theft.

RFID tags with integrated sensors provide not just simply 'electronic bar code' data, but measurements of physical parameters such as temperature, shock (acceleration) and even GPS-enabled tracking. Such sensors can be applied to civil structures, buildings, dams, bridges and tunnels to prevent or, at least, warn engineers of fatigue or failure. Sensors will be deeply embedded within these structures, supplying data when scanned for shear, strain, pressure and other forces that can affect them, using wireless networks to return the scanned results to a data centre, thereby saving the expense of sending out safety inspectors and engineers to monitor the structures.

4.9 Building energy control

Networked RFID devices with physical sensors complement other developments in sensor networks. These combine recent advances in sensor miniaturisation, wireless communication, and micro-system technology to form networks of tiny autonomous sensors that can make accurate measurements of environmental parameters such as temperature humidity, light, acceleration etc. without the necessity of laying cables. Building energy control systems are generally restricted to prestige projects, as the wiring and signal conditioning costs for the many sensors are prohibitive; but the development of these relatively inexpensive devices using radio communications across their network brings the possibility of accurate climate control for all buildings down to individual house level.

One centre of development is University of California, Berkeley, where the next generation of these devices will be as tiny as a few cubic millimetres, and termed 'smart dust' (Berkeley, 2001). Current designs, known as 'motes', are a few cubic centimetres in size, and are already being marketed for building energy control and many other applications – see figure 3 (Crossbow, 2005). Similar devices, BTnodes, are under development in Europe, based on Bluetooth communications technologies (Beutel *et al*, 2004).

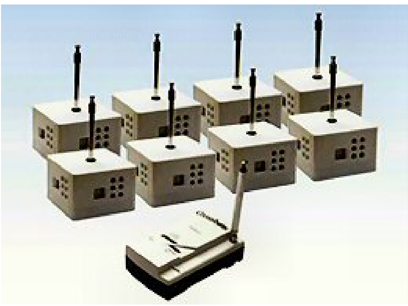

FIG. 3: Mote systems (Crossbow, US)

A problem common to both these developments is battery life; the devices switch on only for brief periods to update measurements and use very short range communications by passing data from one device to the next across the network. For many applications in the built environment, it is impractical to change batteries and some form of solar or other energy support is needed.

Sensor networks, RFID included, can involve the handling of very large quantities of data, and the limited processing capabilities of the mote or BT node devices requires a back-end infrastructure for processing and storage of results. This could well be provided by connection to an external network, the internet for example, linking to a remote database system. Agent technology can be used to minimise data movement, and to provide local control functions where required. In a building management system such functions could provide security alarm functions and detailed energy management at room level.

The future of these devices, once the problems of miniaturisation and cost have been solved, is seen as a fundamental solution to one of the most pressing economic problems of today – runaway energy costs. Once distributed around a building, the sensors would form a network relaying data about each room's temperature, light, humidity, occupancy etc. to a central computer that would regulate energy usage in the building, optimising the energy delivery to each room and using passive heating and ventilation control methods wherever possible. The emerging smart-energy technology could save nations significantly on electricity costs, as buildings currently drain away more than a third of the total energy supply.

5. CONCLUSIONS

The breadth of example applications given above indicate that although it may be slow starting, RFID and its associated sensing and networking technologies are likely to have a major role in facilities management. The comprehensive monitoring it brings may even be seen as invasive and, indeed, there are issues of privacy associated with the technology. However, people tend to accept, albeit reluctantly, speed cameras along roads and CCTV cameras monitoring our movements, so there is unlikely to be substantial opposition to the onward progress of this ultimately beneficial technology. In the specific case of facilities management, pressure to reduce energy and other operational costs through more accurate sensing and control will force the pace. Even so, the cost of deploying RFID technology, especially in existing buildings, will be a deciding factor. This challenge will create commercial opportunities for firms that are able to convince building owners and facilities managers that the balance between cost and benefit has titled in favour of the latter. In the end, it will be cost savings that force the hand of reluctant owners and managers, and possibly the threat of legal action to bring their buildings in line with new legislation. For new buildings, the breakthrough will be helped by perceived and actual gains earlier in the value chain reinforced by the increasing requirement through legislation to reduce energy consumption.

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