Final Report

Full title

Review of the current state of Radio Frequency Identification (RFID) Technology, its use and potential future use in Construction

Acronym

RFID in Construction

December 2006

This report is a co-operation between the following institutions:

The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning

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Executive Summery

Radio frequency identification (RFID) technology is currently being used in such areas as agriculture, athletics, manufacturing, security and law enforcement, and transportation, but few applications have been developed that are related to the construction and facilities operations environment.

Lack of standardisation, high costs of implementation, slow technology development and deployment risks, and the lack of skilled labour are all contributors currently preventing the adoption of new RFID technologies in the construction industry.

Radio-frequency identification (RFID) is an important automatic identification technique with a great potential. RFID tags are categorised as either active or passive. Many organisations are working in various directions to develop chips and reading capability which will give accurate data, easily accessible, at prices, which will make the whole system cost effective.

Radio frequency identification is the next wave in the evolution of computing. Essentially, it's a technology that connects objects to Internet or databases, so they can be tracked, and companies can share data about them. The concept is simple: Place a transponder—a microchip with an antenna—on an item and then use a reader—a device with one or more antennas—to read data off of the microchip using radio waves. The reader passes the information to different computer systems, so that the data can be used to create business value.

The RFID technology can help improve data accuracy by tracking products through supply chains and by identifying products and items/objects at specific points through Automatic Identification (Auto-ID). The technology enables the detection and identification of tagged objects through the data it transmits.

With RFID it is possible to read a tag through the packaging or the product itself. The tag can be read independently of the orientation of the tag – it is not necessary to place the tag on a specific side as it is with the barcode label. Furthermore a significant difference is the amount of labour required – with barcodes a person is required to scan each barcode manually, but RFID scanning is done by readers and does not require labour.

RFID is these days usually associated with the retailing and manufacturing industries, and it must also be admitted that these industries are driving development presently taking into account that major retailers - WalMart, Tesco, Metro etc. - all have set up huge implementation plans for their RFID projects in supply chain on pallets and cases. However a number of industries have applications running and some have had that for a longer period. Some of the leading industries today in adopting RFID technology are retail and food industry, US Department of Defense, Pharmaceutical industry, Healthcare industry and Garments / Apparel industry.

Automated technology implementation in other industries has been substantial. The transformation to automated production and handling in other industries over the past years has resulted in the development of effective practices for considering automation during product development, design, security and supply chain management. An understanding of the practices of other industries could effectively enhance consideration of automated technologies in the construction industry.

Many of the expected benefits to be achieved in other industries should also be achievable likewise in construction and afterwards in maintenance of the buildings. Some of the most important benefits are: (1) Di-

rect and automated surveillance maintenance programmes by a 'click' on a PC or PDA, (2) Inventory control, (3) Control of right equipment at right place and (4) Reduction of data entry errors both during 'production' and afterwards in maintenance.

There are a number of examples and cases of RFID applications from the construction industry today. Many solutions are pilots and are not presently accepted as the normal accepted 'standard' way of performing in construction but have rather the characteristics of trying/using the technology to solve present specific and urgent problems generally - the drivers are not the construction industry itself, but often some vendors and solution providers looking for market opportunities.

In one of the earliest research papers to be found on RFID in Construction it says in the conclusion:

"RFID technology is a promising technology for the construction industry that can be integrated into systems that can track materials, identify vehicles, and assist with cost controls.[1]"

This was in 1995 said at a conference and in the meantime and especially in the last 2-3 years development of the RFID technology has escalated in industries with a huge potential in logistics and supply chain management. A similar development in construction industry is still waiting to be seen. A number of research projects have taken place and research papers have been written all of which more or less conclude the same as above. There are a number of barriers to break and challenges to meet, so therefore research and innovations are needed to overcome these in the future.

There are many driving forces for the RFID-technology. One could say that before a group of international retailers with the American WalMart in front put efforts into developing open standards and funded large R&D projects (Auto-ID centre) there was no interest in the technology. This is definitely not true as many of the examples in this report also show in detail. However the constant push from the big actors in supply chains has brought development forward to a situation where even small companies in a few years will be able to afford and benefit from the technology.

In the recent published research from the Danish Building Research Institute (SBI) "Embedded technology in Construction" it says[2]:

"In the construction value chain from manufacturer of building materials, distributors, constructors, operators and end-users many advantages can be achieved from embedded technology (RFID). However there are very different demands and needs to performance of technology in the different groups."

The expectations for RFID in Construction are high and the benefits obvious.

At this stage in use and development of RFID in Construction we must realise that there are many questions and few answers, most cases that we have been investigating are pilots and not full-scale implementations, many research papers and development projects have caused great interest and many observers but not any steps into fulfilment of RFID strategies.

[1] 'Radio-Frequency Identification Applications in Construction Industry' - Edward J. Jaselskis et al. - Journal of Construction Engineering and Management, June 1995

[2] www.sbi.dk - report in Danish June 2006 - "Embedded technology in Construction" - (potential savings in construction for public building)

RFID in construction offers a great deal of potential for industrial innovation and efficiency improvements, but there are still some considerable obstacles to overcome such as:

- Immature application of advanced logistics systems and the absence of information and identification systems in the construction industry.
- Lack of awareness of RFID's potential in the construction industry.
- Low RFID-knowledge and awareness in the construction sector
- Lack of robust RFID-initiatives in the construction industry
- Lack of successful RFID-implementation cases that thoroughly shows its potentials
- The traditionally less industrialised construction industry and its relatively negative attitudes towards new innovations and technology

We believe that there is a need to provide support and funding to actors, organisations and institutions in order to overcome the obstacles and therefore it is recommended to encourage and support specific actions that increase the knowledge of RFID-technology in the construction sector as such.

There are several areas where different initiatives can be taken to advance the progress of the RFID development in construction industry.

These are in the areas of:

- RFID best practices
- Education on RFID technology
- Standards for RFID technology
- RFID innovations
- Research on RFID technology

The different recommendations are given in detail in chapter 8. In many instances, these efforts should be joint co-operation by the public and private sectors.

The report and especially the recommendations are focused on examples on pilots, applications and research themes related and connected to RFID in construction. We are in the report having a technical view on RFID but acknowledge that there are also organizational and socio-political aspects of implementing RFID in an industry or organization.

Although we recognize that these aspects are very important when implementing new technologies in industries and organizations and especially in such a fragmented industry like the construction industry we have not included such research examples in our report as we are of the opinion that this is not a special RFID technology issue but more or less an issue that will be important for any technology and in any industry.

The recommendations contain a number of RFID pilot cases and studies, but it should be explicitly pointed out that the overcoming of barriers is an issue of an integrated approach between technical organization, training programmes, competences and management.

Financing or funding the proposals and recommendations has not been taken into account in this report. Some may be financed locally by institutions, organisations or even governments; some may get the financing via EU funds. Others may find the financing on a pure market basis. However this has not been part of the objective.

1. Introduction

The **overall objective** of this review of RFID IN CONSTRUCTION is to get an overview of the present application of RFID technology in Construction and to present recommendations for further research into RFID in Construction.

More specifically the **objectives** of the project can be summarised as follow,

- The review is intended to provide The Funders with an overall view of the uses being made or being researched for the use of RFID in construction.
- To provide a context for considering the wider application of RFID in construction (and ongoing management of structures, buildings and their components).
- To enable The Funders to take a view on where research may head in the future.
- To provide a resume of the non-construction related uses of RFID technology together with a brief overview of the advances in RFID technology that are being developed.
- To provide advice on how further use of RFID in construction could be encouraged and potential useful areas for future research. These considerations should some how be evaluated from a "quick wins" situation and a larger and longer perspective of research.

Radio **F**requency **ID**entification (RFID) is an old technology which was already in use for "friend or foe" recognition for anti-aircraft gun shooting in World War 2. Since then RFID has been taken into use for many other purposes, i.e. securing against theft of goods, bridge crossing fees, car keys etc.

The new importance of RFID is connected to certain measures which a group of the world's biggest retail chains and brand suppliers initiated under the name of Global Commerce Initiative at the end of the 1990'es. The interesting part of the vision is that in the same way as it applies to the bar codes, one set of worldwide standards is sought established which can be coded and read by everyone globally.

The above observations underline the fact that many initiatives are taken in the name of conducting good efficient solutions for tracking/tracing in supply chains. And many good solutions are also found today for different industries. However still no unified solutions have found a global implementation except the one of EAN/UPC barcodes that is used globally.

We have been working in four phases in the process of creating this review and recommendations in RFID in Construction: *Mapping – Focusing – Scenario – Recommendations*.

1. Mapping

Activities

Desk Research, Mapping – we have used these methods to find information on RFID in general and on RFID in construction in particular via the Internet, internal and external networks, etc. Here we have found different examples, cases and best practice on RFID in the different parts of supply chain and different industries.

We have also be looking for different research and vision papers national and international for construction industry with relevance to RFID or other related technologies.

The results of this phase is covered in the chapters 2 (Auto-Id technologies), chapter 3 (RFID in different industries) and chapter 4 (RFID in construction today).

Also in appendix I a number of RFID-cases and pilots within the construction industry have been listed and in appendix II a number of resent RFID research project within the industry.

2. Focusing

Activities

Interview – based on a mutual developed questionnaire we have be interviewing major actors in construction (3-5 pr. country), covering different parts of the industry and in supply chain. The same questionnaire has been used in interviewing the expert panel.

Workshops and panel discussions – we have invited representatives from construction industry, organisations, RFID/ICT experts to workshops/panel discussions on a national basis to discuss outcome of different research results and have here sought inspiration for visions, future trends and recommendations.

The result of this phase is covered in chapter 5 (Drivers for RFID) and partly in chapter 6 (RFID in future construction).

3. Scenario

Activities

Future workshop **–** we have been using this technique in a virtual version using the Internet in communication across countries to create different scenarios for RFID in Construction.

Participants in this part of the process have been researchers, developers and consultants from the research institutes.

The result of this phase is covered partly in chapter 6 (RFID in future construction) and in chapter 7 (R&D in construction).

4. Recommendations

Activities

Main report including recommendations is written. Exchange of a number of drafts between the partners until final report is delivered.

The result of this phase is covered in chapter 8 (Recommendations).

Behind this report is a group of research institutes covering,

- Danish Technological Institute, - *project holder and project leader*
  - Building and Construction Division
  - Productivity and Logistics Division
    - RFID Test and knowledge Centre
- Salford University, Greater Manchester University, UK
  - School of Construction & Property Management
- VTT Technical Research Centre of Finland
- Prolog Bygglogistik AB, Malmö and Lund University, Dept. Of Industrial Management and Logistics, Sweden

Besides this the group has had access to international experts within RFID and ICT.

The group together with the experts represents researchers, senior research scientists, senior consultants, chief consultants covering:

- Expertise in construction, lean construction, ICT in construction, i.e. operation, consultancy, systems development, implementation
- Expertise in ICT-development, systems and applications
- Expertise in logistics, supply chain management and lean production
- Expertise in product ID, standards, bar-coding and RFID-technology
- Expertise within change management processes, technology foresights, and vision management
- Networks within construction, supply chain management, ICT, product ID, facilities management, asset management

The report and especially the recommendations are focused on examples on pilots, applications and research themes related and connected to RFID in construction. We are in the report having a technical view on RFID but acknowledge that there are also organizational and socio-political aspects of implementing RFID in an industry or organization.

Although we recognize that these aspects are very important when implementing new technologies in industries and organizations and especially in such a fragmented industry like the construction industry we will not include such research examples in our report as we are of the opinion that this is not a special RFID technology issue but more or less an issue that will be important for any technology and in any industry.

2. Auto-ID - technologies

Auto-ID is the terminology for technologies for identification of items, objects and products. A number of ID-systems are presently in use. Among the best known and widely spread are,

- Barcodes - GTIN (former EAN/UPC)
- Datamatrix - 2D standard code
- PDF 417
- RFID-tags

Barcodes – Set of barcodes - GTIN (former EAN/UPC) and SSCC important and widely used - The main GS1 identifier is the global trade item number or GTIN. This is a number identifying any item traded in the global supply chain that will be priced, ordered or invoiced. The GTIN contains no information: it is used as a key to information held on a database. Each separate product line and packaging level will be assigned a different number or GTIN. A Global Trade Item Number™ may use the EAN/UCC-8, UCC-12, EAN/UCC-13, or EAN/UCC-14 Data Structure. Barcodes are used in most industries and for multiple purposes.

Data Matrix - is a symbol that can be etched or printed very small. It can be particularly helpful in marking small parts of small items such as electronic chips for part number and traceability information. The code is a two-dimensional matrix symbol. The encodeable character set of 128 characters conforms to ISO 646 with a user defined extended character set of 256 characters. Error correction may be applied. CCD scanners are used. Data Matrix is an ISO standard.

PDF417 - is a multi-row, variable-length symbol with high data capacity and error-correction capability. As it is more of a stacked code with very low bars and spaces, some lasers or two-dimensional imaging devices can read it. Every PDF417 symbol contains a minimum of 3 to a maximum of 90 rows. A symbol character consists of seventeen modules arranged into four bars and four spaces. PDF417 is an outstanding portable data file, which can contain substantial information in a relatively small area yet, be easily read to yield full information on a subject or item without access to a database. Uses include medical histories, hazardous material data sheets and full manifest content data to accompany shipments.

RFID-tags - Radio-frequency identification (RFID) is an important automatic identification technique with a great potential. RFID tags are categorised as either active or passive. Many organisations are working in various directions to develop chips and reading capability which will give accurate data, easily accessible, at prices, which will make the whole system cost effective. A huge research and development project was initiated in 1999 and run by Auto-ID-Centre managed by MIT in Boston, USA and Cambridge University, UK. This closed down in 2003 and the research results transferred to the organisation EPCglobal who has now continued the standardisations related to the retail industry world-wide. Leading international producers of retail brands and supermarkets has been sponsoring the project and is today driving forces in the development.

Below is a comparison on the most frequent used barcodes and RFID:

Table 01	Barcodes (EAN/UPC) GTIN - SSCC	Datamatrix 2D	PDF417	RFID-tags	
				Active	Passive
Price	Very low	Relatively low	Relatively low	Very high	High – decreasing re vision 5c tag
Operating Costs	Low	Low	Medium to Low	High	Relatively high
Printing tolerance	High	Medium	Medium	N/A	N/A
Reading tolerance	High	Medium	Medium	Normally none Some frequency problems	Normally none Some frequency problems
ID after damage	Not readable	Error correction algorithm available	Error correction algorithm available	Protected by build-in solutions – damaged, however un-readable	Protected by build-in solutions – damaged, however un-readable
Reading equipment	All normal vision reading types	CCD scanners	Laser scanners or 2D imaging de-vices	Antennas, readers and batteries in tags	Antennas, readers also handheld and mobile terminals
Size Code for ID	Relatively small	Small	Substantial infor-mation in a rela-tively small area	Label (large) or build into the product	Different sizes and lengths
Variable-Length	N/A	Yes	Yes	Unlimited infor-mation build into tags	UHF EPCglobal GEN2 128/256 bits, others available
Readable/ access to database	Information is not readable without access to data-bases	Scanned informa-tion without access to a database	Scanned informa-tion without access to a database	Information automatically transferred	Access to infor-mation direct
Build-in 'intelligence'	None	None	None	Active Intelli-gence	Not normally
Overall investments	Relatively small	Relatively low	Relatively low	Very high pres-ently	Very high pres-ently
Standardisation	Full standardised	128 characters conforming to ISO 646	Industry standards	Different stan-dards presently – future vision on global stan-dard	Industry stan-dards, presently only UHF as global standard
Overall usage	Relevant in all supply chains especially in FMCG	Used mainly in aircraft/airframe and pharmaceuti-cal manufacturing industry Pilot project see below.	Used widely in automotive indus-try world-wide	Credit card shaped for use in access appli-cations in many industries.	All shapes for use in different applications. Widely used for anti-theft hard plastic tags in stores.

RFID Basics

Radio frequency identification is the next wave in the evolution of computing. Essentially, it's a technology that connects objects to Internet or databases, so they can be tracked, and companies can share data about them. The concept is simple: Place a transponder—a microchip with an antenna—on an item and then use a reader—a device with one or more antennas—to read data off of the microchip using radio waves. The reader passes the information to a computer, so that the data can be used to create business value.

RFID technology that can help improve data accuracy by tracking products through supply chains and by identifying products and items/objects at specific points through Automatic Identification (Auto-ID). The technology enables the detection and identification of tagged objects through the data it transmits.

Differences in barcode and RFID technology

RFID is said to have a revolutionizing effect, but some of the benefits can also be achieved already through better use of current barcode systems or by using alternatives like the 2-D barcode, where the barcode technologies presently are substantially cheaper than the RFID tag.

As mentioned earlier, the project will not focus on alternative technologies, but still, in order to give a better understanding of how RFID works, we find it useful to compare it with the barcode.

The main difference is that RFID does not require line of sight as bar-coding does. With RFID it is possible to read a tag through the packaging or the product itself. The tag can be read independently of the orientation of the tag – it is not necessary to place the tag on a specific side as it is with the barcode label. Furthermore a significant difference is the amount of labour required – with barcodes a person is required to scan each barcode manually, but with RFID scanning is done by readers and does not require labour.

Figure 01

Tags come in different memory sizes, they can contain a lot of information, and they can be used throughout the supply chain. The data capacity of the RFID tags enables it to carry more information than the barcode. Tags can stand both heating and cooling, and can therefore be used in the production process. Contrary, the barcode is much more fragile, because fluids and rough handling may destroy the readability.

Mass serialization, or the ability to store a unique serial number for each and every item, is something that cannot be accomplished with traditional barcodes where the number is related to the product category. However, with 2-D barcodes, it is possible to achieve mass serialization, and some people may therefore see this as an alternative to RFID. Still, barcodes cannot offer all the advantages achievable with RFID.

There are many different types of RFID systems, and installing them and using them to generate data that can be used to cut costs or boost efficiency is challenging. It's important to choose the right type of RFID system for a particular application. It's also important to work with an experienced systems integrator to make sure the system is installed and configured properly.

The vast majority of RFID tags or transponders (the tags are often used interchangeably) use a silicon microchip to store a unique serial number and usually some additional information.

There are three types of tags passive, active and semi-passive/semi-active. Passive tags are the most popular type, because of their low cost. They do not have a battery, but instead they get their power from the RFID reader. The active tags have an on-tag power supply like a battery, which emits a constant signal containing identification information.

Semi-passive/semi-active tags have a battery, but it is only activated when it is in the reader's field.

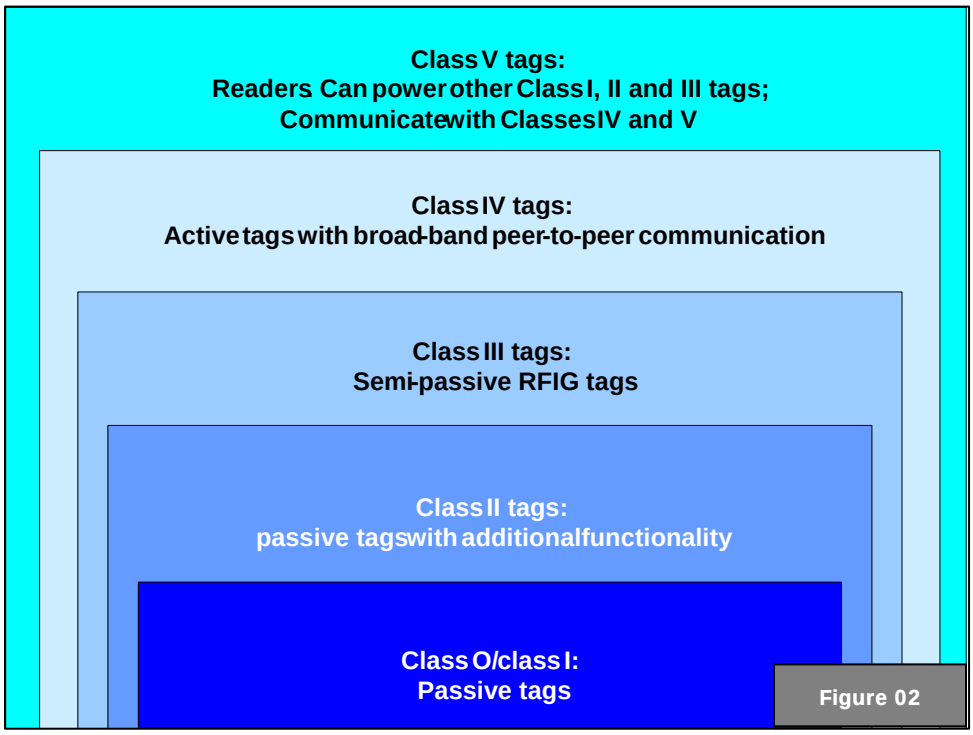


Figure 02

Passive RFID systems are the most promising to provide low-cost ubiquitous tagging capability with adequate performance for most supply chain management applications. (See figure 02)

Passive RFID

Passive RFID tags have no power source and no transmitter -also called Class 0 or Class I. They are cheaper than active tags (see below) and require no maintenance, which is why retailers and manufacturers are looking to use passive tags in their supply chains. They have a relatively shorter read range than active tags (a few inches to 30 feet, depending on the frequency).

A passive RFID transponder consists of a microchip attached to an antenna. The transponder can be packaged in many different ways. It can be mounted on a substrate to create a tag, or sandwiched between an adhesive layer and a paper label to create a printable RFID label, or smart label. Transponders can also be embedded in a plastic card, a key fob, the walls of a plastic container, and special packaging to resist heat, cold or harsh cleaning chemicals. The form factor used depends on the application, but packaging the transponder adds significantly to the cost. Read-only tags are typically passive and are programmed with a unique set of data (usually 32 to 128 bits) that cannot be modified. Passive tags are lighter, have smaller form factors and are less expensive then the more powerful active tags.

Passive tags can operate at low frequency, high frequency and ultra-high frequency. Low-frequency systems generally operate at 124 kHz, 125 kHz or 135 kHz. High-frequency systems use 13.56 MHz, and ultra-high frequency systems (UHF) use a band anywhere from 400 MHz to 960 MHz - the world more or less is divided into three regions with regard to frequencies, 1) Europe and Africa that mainly operates on 866 MHz, 2) North- and South America that operate between 902-928 MHz and 3) Australia and Asia that operates around 915 MHz. Some systems also use 2.45 GHz and other areas of the radio spectrum.

Radio waves behave differently at each of these frequencies (see illustration in later chapter), which mean the different frequencies are suitable for different applications. They can penetrate walls well, but can't go through metal. Low-frequency tags are ideal for applications where the tag needs to be read through mate-

rial or water at close range. Waves in the UHF band are also absorbed by water. The big challenge facing companies using UHF systems is being able to read RFID tags on cases in the centre of a pallet, or on materials, products and objects made of or containing metal or water.

Active RFID

Active tags are used on large assets, such as cargo containers, rail cars and large reusable containers, which need to be tracked over long distances (in a distribution yard, for example). They usually operate at 433 MHz, 2.45 GHz, or 5.8 GHz, and they typically have a read range of 20 meters to 100 meters (60 feet to 300 feet).

Basically there are two types of active tags: transponders and beacons. Active transponders are woken up when they receive a signal from a reader. These are used in toll payment collection, checkpoint control and other systems. When a car with an active transponder approaches a tollbooth, a reader at the booth sends out a signal that wakes up the transponder on the car windshield. The transponder then broadcasts its unique ID to the reader. Transponders conserve battery life by having the tag broadcast its signal only when it is within range of a reader.

Beacons are used in most real-time locating systems (RTLS), where the precise location of an asset needs to be tracked. In an RTLS, a beacon emits a signal with its unique identifier at pre-set intervals. The beacon's signal is picked up by at least three reader antennas positioned around the perimeter of the area where assets are being tracked. RTLS are usually used outside, say, in a distribution yard, but automakers use the systems in large manufacturing facilities to track parts bins.

Active tags can be read reliably because they broadcast a signal to the reader. The prices are rather high (compared to passive tags), depending on the amount of memory, the battery life required, whether the tag includes an on-board temperature sensor or other sensors, and the ruggedness required. A thicker, more durable plastic housing will also increase the cost.

Active systems usually perform better than passive systems in highly metallic environments and rough weather conditions. Because they carry a local power source, active RFID tags can be expanded and adapted to include additional memory and local processing. They can read, write, and store significant amount of data. They can be attached to sensors to store and communicate data to and from these devices.

UHF, low or high frequencies?

All focus is presently on the use of UHF passive systems in the supply chain, rather than low-frequency and high-frequency systems – why is that?

One reason is some vendors in the UHF market have offered simple, low cost tags. Another important reason is read range. Companies need to be able to read tags from at least 3.3 meters (10 feet) for RFID to be useful in a warehouse. That's because there is no way to read a tag on a pallet going through a dock door from less than 3.3 meters. At closer distances, the reader begins to interfere with the normal operation of forklifts and other equipment. Low-frequency tags can usually be read from within 0.33 meter (12 inches). High frequency tags can be read from 0 – 50 cm, and UHF tags can be read from 1 - 5 meters (3 - 10 feet) or more.

As it can be seen in the RFID frequency chart (table 02) a number of applications and industries are using different frequencies. We will in a later chapter describe the characteristics of these solutions.

Table 02

RFID Frequency Chart

DANISH TECHNOLOGICAL INSTITUTE

Frequency RFID Technology	Low Frequency 125 - 135 kHz	High Frequency 13,56 MHz	Ultra High Frequency 400 - 960 MHz	Microwave 2,45 - 5,8 GHz
Availability	*> 30 years*	*> 10 years*	*US > 3 years, EU relatively new*	*> 10 years*
Standardisation	*ISO 11784/5 ISO 14223, ISO 18000-2*	*ISO 14443 ISO 15693, ISO 18000-3*	*ISO 18000-6, EPCGen1 and2*	*ISO 18000-4*
Subsurface (except metal)	*No impact*	*Low impact*	*Depends on material*	*No impact*
Fluids	*No impact*	*Low impact*	*High impact*	*High impact*
Readability on metal	*Limited*	*Bad, special tags available*	*Limited*	*Good*
Bulk reading	*Limited*	*Up to 50 tags/sec*	*Up to 150 tags/sec*	*??*
Reading distance	*~ 0 - 100 cm*	*~ 0 - 50 cm*	*US ~ 0 - 500 cm, EU ~ 0 - 300 cm*	*~ 0 - 500 meters, active tags*
Data transmission rate	*Low*	*Medium*	*Fast*	*Very fast*
Interference resistance	*High*	*High Frequency*	*Depends on environment*	*Susceptible to electronic noise*
Typical application	*Animal ID, Beer kegs, Car anti theft, Access control, Personal ID*	*Track and tracing, Cooling chain control, Person ID, Item level tagging*	*Supply chain management (SCM), Pallet and container tracking, Trailer tracking in shipyards, Pallet and case tagging*	*Toll collection, Real time location systems, Long range access control vehicles, Aircraft part maintenance*
Industrial sectors	*Farming, Slaughterhouse, Brewery*	*Airport, Slaughterhouse, Pharmaceutical, Healthcare, Production, SCM product level*	*Production, SCM on pallet and colli level*	*Army, Shipping, Airlines and Government*
Other	*Oct. 2004 FDA approved a 134 kHz from VeryChip that can be implanted in humans*			
Market developers			*EPCglobal, US: Wal-Mart, DOD, FDA, EU: Metro, Tesco, Carrefour*	*Governments, Boeing, Security and safety companies*

Inductive vs. Propagation Coupling

Read range is determined by many factors, but one of the most important is the method passive tags use to transmit data to the reader. Low- and high-frequency tags use *inductive coupling.* Essentially, a coil in the reader antenna and a coil in the tag antenna form an electromagnetic field. The tag draws power from the field, uses the power to run the circuitry on the chip and then changes the electric load on the antenna. The reader antenna senses the change in the magnetic field and converts these changes into the ones and zeros that computers understand. Because the coil in the tag antenna and the coil in the reader antenna must form a magnetic field, the tag must be fairly close to the reader antenna, which limits the read range of these systems.

Passive UHF systems use *propagation coupling.* A reader antenna emits electromagnetic energy (radio waves). No electromagnetic field is formed. Instead, the tag gathers energy from the reader antenna, and the microchip uses the energy to change the load on the antenna and reflect back an altered signal. This is called backscatter.

UHF tags can communicate ones and zeroes in three different ways. They can increase the amplitude of the wave coming back (amplitude shift keying), shift the wave so it's out of phase (phase shift keying) or change the frequency (frequency shift keying). The reader picks up the signal and converts the altered wave

into a one or a zero. That information is then passed on to a computer that converts the binary data into a serial number or the data stored on the tag.

Factors that affect performance

It's not necessary to understand the details of the communication methods used, but end users do need to understand the basic characteristics of the different systems and what affects their performance.

Because low- and high-frequency systems use inductive coupling, the size of the reader field is smaller and can be more easily controlled. Ultra-high frequency systems that use propagation coupling are harder to control, because energy is sent over long distances. The waves can bounce off surfaces and reach tags you never expected them to reach; you might even read tags you don't want to read.

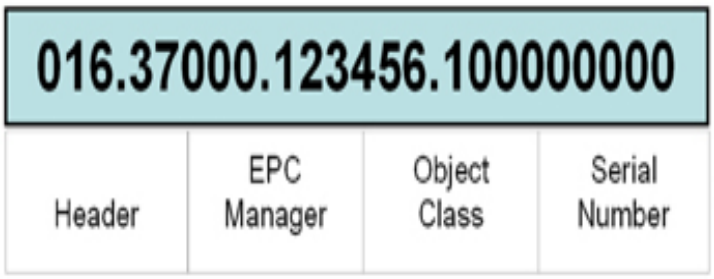
Low- and high-frequency systems also work better than UHF systems around metal and water. The radio waves do not bounce off metal and cause false reads. And they are better able to penetrate water; UHF radio waves are absorbed by water. In fact, the problem with reading tags reliably is mainly an issue with UHF systems.

The amount of information stored on a tag depends on whether it is an active or a passive tag, and furthermore the information can be configured in different ways; read-only, write-once-read-many and read-write.[3] Tags also have the ability to monitor measure and record numerous environmental conditions, when combined with a sensing device

EPCglobal - presently only UHF

An important issue when dealing with RFID technology across the supply chain is the level of compatibility. The compatibility refers to the RFID standards used. Several different standards are developed and applied to the RFID technology, which can vary between industries and countries. To cope with the degree of compatibility a global technical standard code, EPC standard, has been developed.

Figure 03 Illustration of an EPC



Source: http://www.epcglobalus.org

Electronic Product Code (EPC) is the next generation of product identification and supports the use of RFID. It is a unique number, which identifies a specific object in motion in the supply chain.[4] Using an EPC makes unique identification of all products possible. EPC is divided into numbers, which can identify the manufacturer and product type, and it uses a serial number to identify unique items.

An EPC number contains of:

- Header, which identifies the length, type, structure, version and generation of EPC
- Manager number, which identifies the company or company entity
- Object class, similar to a stock keeping unit or SKU
- Serial number, which is the specific instance of the object class being tagged.

[3] Twist (2005)

[4] www.epcglobalinc.com/about/faqs.html#6

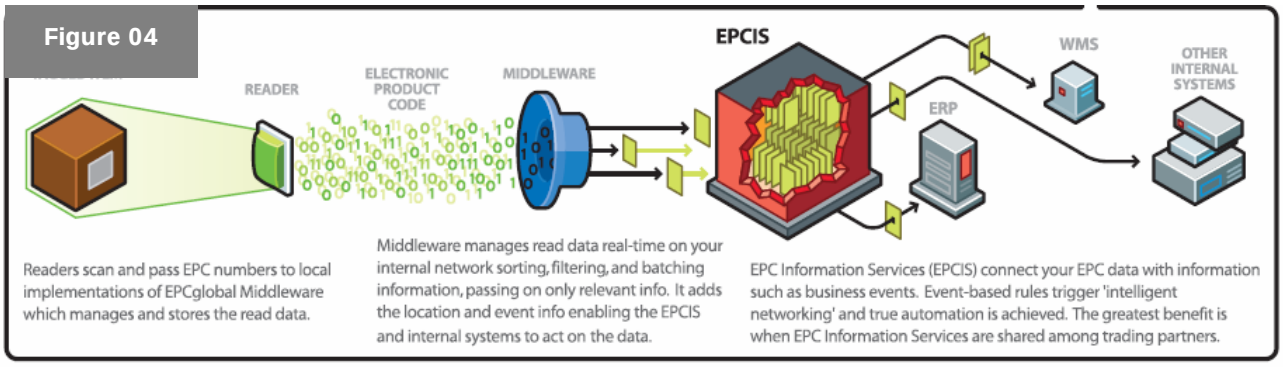
The EPC number is attached to a tag, and by using RFID, EPC can communicate its numbers to a reader, which passes them on to a computer system. When a tag is encoded with EPC it will allow the pallets, cases and, eventually, individual items to be tracked through the supply chain.

EPC Generation 2 is the standard, which is agreed upon. It was developed in a collaboration of leading RFID users and vendors, working through EPCglobal. The full name of what is popularly called EPC Generation 2 is actually EPC Class 1 Generation 2. The specification refers to the second major release of a specification for a tag with write-once memory.[5] The EPC Class Structure describes a tag's basic functionality – for example whether it has memory or a battery, whereas Generation refers to a tag specification's major release or version number. These specifications provide many options, and for a tag to be fully compliant it has to offer everything of the above. A reader does not need to have all of these options but can instead be chosen and adjusted to specific requirements and circumstances.

Other Generations will succeed Generation 2. Around 2006/2007 Generation 3 tag will be introduced to the EPC standards development process. A transition period will take place, but eventually Generation 3 will penetrate the market and replace Generation 2 – therefore the RFID technology has to be geared to and ready for constant development and progressing.[6] The EPC network is just one of the many ways in which RFID data can be shared. The standard requirements for data capturing and forwarding is basically a middleware system, which can handle the data, and a web server that can communicate the data collection.

EPCglobal illustrate the data capturing process like this:

Figure 04



Security and Privacy

One of the most important challenges in convincing users to adopt emerging technologies is the protection of data and privacy and this is also an important issue with the RFID technology. Concerns over data protection are widespread, particularly as sensors and smart tags can be tracked or manipulated unless special security precautions are taken.

When all items in the future come equipped with tags and some of those contain vital data combined with computing and communication capabilities, concepts of data request and data consent risk becoming outdated. There have been some discussions on security breach related to an RFID deployment but so far no actual examples - yet. Businesses and vendors alike acknowledge that security remains a question mark and that it has not so far been highly prioritised compared to the focus on bottom-line results and returns on investment for RFID-enabling the supply chains. With a technology as ubiquitous as radio-frequency identifi-

[5] ThingMagic (2005)

[6] ThingMagic (2005)

cation will be, there's great potential for damage. There is also a risk of damage on barcodes but with RFID, it becomes a freeway. That is why all industries will need to get its security house in order.

A number of security measures already exist, but not all of them are being considered for adoption by the EPCglobal Network, which provides the infrastructure for sharing RFID-enabled information about products in the supply chain. EPCglobal maintains the electronic-product-code database, which identifies a manufacturer, product, and version and serial number; provides middleware specifications for data exchange; and administers the Object Name Service for matching an electronic product code to information about the associated item.

The good news is that the industries are paying more attention to the security issue now but much research and developments are still needed in many fields.

We will not go further into this here and not come to any conclusions in this report as this is not a specific constructions industry problem but a more general challenge for the technology as such.

Much research on this topic is already taking place and more will come in the very near future.

3. RFID in Different Industries

RFID is these days usually associated with the retailing and manufacturing industries, and it must also be admitted that these industries are driving development presently taking into account that major retailers - WalMart, Tesco, Metro etc. - all have set up huge implementation plans for their RFID projects in supply chain on pallets and cases.

Presently RFID is in progress from test and development to the operating phase with a number of global retail chains and authorities:

Table 04

Requesting party	Requirement announced date	Deadline Start	Number (plans if stated)
WalMart	June 2003 August 2003	January 2005 January 2006	End 2006 more than 1,000 suppliers in 2006 Start 2007 1,000 shops in EU
Tesco	November 2003	September 2004 (non food started)	Priority non food and returnable assets, but do their own labelling for the time being. Bought 4,000 readers and 16,000 antennas (2005).
Metro AG	January 2004	November 2004	2006 - 2007 all in Germany
Target	February 2004	Spring 2005 (top100)	Spring 2007 (all)
Albertson's	March 2004	April 2005	(Top 100)
Carrefour	March 2004		Pilot projects in DC Vert-Saint-Denis (Paris) with returnable assets
Best Buy	August 2004	January 2006 (top 100)	May 2007 (all)
DoD US Dept. of Defense	September 2003	January 2005 January 2006	Top 400 suppliers All 45,000! suppliers
FDA US Food and Drug Administration	February 2004	2005-07	FDA allows RFID pilots on pharmaceuticals. 2 States (CA, FL) have put new claims on pharmacy pedigree and marking which points to RFID as a solution.

However a number of industries have applications running and some have had that for a longer period. The characteristics of these will be described in the following. The descriptions are presented in order of importance and industries with large volumes.

Description of different sectors and applications:

A. Retail industry - Supply chain management

Some supermarkets are already today tagging pallets, cases and other returnable items, such as plastic crates used for fresh foods. Tagging the crates gives total asset visibility and allows better management of the asset pool. The ability to write to the tag also allows the addition of information such as the contents of the crate, sell-by date and manufacturer.

Today some of the leading retailers are the front runners in implementing RFID into worldwide logistics. As shown earlier in table 04, WalMart has demanded the top suppliers to deliver pallets and boxes with EP-Cglobal UHF tags. By the end of year 2006 there will be 1,000 suppliers, who will deliver pallets and boxes with RFID tags. So fare the implementation has been at DC's and stores in USA, but from beginning of 2007 WalMart will also start implementing RFID in their more than 1,000 stores in UK and Germany.

The prices of RFID tags are still too high to implement widely on item level. Until now it is only items with high value like Gillette razorblades, that are tagged, and the tags here are also used as anti-theft protection.

The main reason for the retailers to implement RFID is cost savings. The large savings will be reduction in manual scanning of pallets and boxes. WalMart has estimated that every manual scanning costs 5 US cent. With 6 billion boxes going through WalMart every year, it is clear that WalMart should be able to save large amounts by eliminating manual scanning.

Other big retailers who are implementing RFID and demanding their suppliers to deliver pallet and boxes with EPCglobal UHF tags are Tesco, Metro Group, Target, Albertson's, Carrefour and Best Buy.

For the European companies the implementation is not without problems, since the allowed bandwidth in EU is much smaller than in the US. US companies have 24 MHz bandwidth (902-926MHz), while EU companies only are allowed to operate on 2 MHz bandwidth (865.6-867.6MHz). This is giving problems if more readers are operating in the same area.

B. Food industry

The major driver for RFID tagging in the food industry is the EU demand for traceability. With RFID technology it is much simpler to get traceability in the supply chain. Since 2005 EU legislation[7] has demanded full traceability on food and feedstuff for cattle. The RFID tagging is used on different levels internally in the production line, where 125 KHz or 13.56 MHz tags are used. For example in Slaughterhouses where the flesh hook trees are equipped with RFID tags, in this way it is not only possible to trace a truck load of animals, it is no possible to trace each animal during the slaughtering.

After the products are packed, UHF tags (866-930 MHz) will be used. It is now a demand from many of the big retailers like Wal-Mart, Albertson's, Target, Tesco, Carrefour and Metro, that pallets are tagged with an UHF tag, and shortly it is expected to be a demand that products are also tagged on case level to all the big international retailers.

C. The US Department of Defense (DoD) RFID Background[8]

Early experience with Radio Frequency Identification (RFID) began when the Army installed active, data rich RFID technology at selected sites around the world to track containers through the logistics pipeline and to provide stand-off visibility of container contents. Fixed interrogators installed at key nodes read RFID tags attached to pallets or containers and provided data to a regional server prior to passing the data to the global asset visibility systems. During the latest operation in Iraq, the use of active, data rich RFID tags was mandated for all materiel entering into operation.

The use of RFID in the DoD supply chain has the potential to provide real benefits in inventory management, asset visibility, and interoperability in an end-to-end integrated environment. RFID encapsulates the data

[7] http://www.packwire.com/news/ng.asp?n=62320-idtechex-wal-mart-rfid

[8] http://www.acq.osd.mil/log/rfid/

accuracy advantages inherent in all types of automatic identification technology (AIT). Additionally, RFID is a totally non- intrusive methodology for data capture (requires no human intervention), is non- line of sight technology, and is a technology that may possess both read and write options within the same equipment item. RFID addresses a key challenge that has been noted at every node within the DoD supply chain – lack of visibility of item data. As an integral aspect of the overarching suite of AIT capabilities, RFID will become a key technology enabler for the DoD logistics business transformation and will support long-term integration of the Unique Identification (UID) into the DoD end-to-end supply chain. RFID (both active and passive) is required by DoD to:

- Provide near-real time in-transit visibility for all classes of supplies and materiel
- Provide "in the box" content level detail for all classes of supplies and materiel
- Provide quality, non- intrusive identification and data collection that enables enhanced inventory management
- Provide enhanced item level visibility

To take maximum advantage of the inherent life-cycle asset management efficiencies that can be realized with RFID, the Under Secretary of Defense for Acquisition, Technology, and Logistics issued policy 1) directing the use of high data capacity RFID used in the DoD operational environment and 2) requiring that suppliers put passive RFID tags on the lowest possible piece part/case/pallet packaging by January 2005. In this regard, DoD is leveraging Electronic Product Code (EPC) and compatible RFID tags.

D. Pharmaceutical industry

The e-pedigree is a hot topic in the pharmaceutical industry. The origin of pharmaceuticals has to be verified on the item-level. There is also need for anti-counterfeiting procedures. The utilization of RFID empowers safe and secure supply and administration of pharmaceuticals. Therefore the industry[9] is mainly interested in tagging at item level.

At the same time the FDA (USA) is recommending that all item level prescribed drugs supplied into the US market should be RFID tagged. Originally the FDA wanted pharmacy products tagged from the beginning of year 2006, but this has not happened. Now FDA commissioner Andrew Von Eschenbach[10] has asked the FDA's Counterfeit Drug Task Force to give an account in a report, with recommendations of how the board should act in order to ensure that RFID is introduced in the medical products supply chain soon.

Another use of RFID in the pharmacy industry is to ensure the cooling chain. It is possible, with an RFID tag that fits on the bag side of the product label, to see if the cooling chain has been broken.

E. Healthcare industry

In hospitals RFID tags can be used to identify patients. On the wristband the patient is wearing, while hospitalized, it is possible to put an RFID tag. The tag can be used to identify the patient before surgery, to ensure that the right procedures are performed, and to ensure that no allergic reaction occurs, due to wrong medication. In the U.S. as many as 98.000 people are said to die every year due to "mistakes" in medication or misidentification[11]. In some hospitals in Western Australia[12], active tags are used to identify and track newborns. After there has been an incidence with a kidnapping of a newborn, one hospital has installed an active RFID system, which can trace the newborns and set an alarm if the tag comes too close to the exit.

[9] http://www.rfid.IDtechEx.com

[10] http://www.packnews.dk

[11] http://www.pangonetworks.com/documents/mobilehealth_041210.pdf

[12] http://www.pcworld.idg.com.au/index.php/id;484455565;fp;2;fpid;1

RFID is also used for asset management. With an active tag on the equipment, it is not only possible to see the location of the equipment; it is also possible to see whether the equipment is in use, available or need to be serviced. In emergency situations it is crucial what the staff has the right equipment at hand, and with this tracking system, it is possible to locate equipment wherever available.

One problem with use of RFID in the healthcare industry is that the normal frequency's used for RFID, is also used for some of the equipment in the hospitals. Since it cannot be allowed to interfere with the hospital equipment, it is necessary, to use other frequencies. These can be either low in the UHF band, like 303 MHz[13] or in the microwave band up to 10.6 GHz[14].

F. Garments - Apparel Industry

Incorporating RFID tags into garment labels or even into the garment itself can be a valuable tool for brand owners. A tag inserted at the garment manufacturing plant can identify its source. By using the tag's unique identification number, the garment can be certified as authentic, which enables the identification and control of counterfeits. Grey market imports can be controlled through the use of source identity. The tags enable inventory visibility throughout the supply chain, reducing shrinkage and out-of-stocks, and the EAS function can reduce in-store theft. Finally, where warranty information is needed for after-sales service, the tag can be written to at the point of sale.

G. Parcel and post

RFID is being used today in the postal environment to enable improved item tracking during the sorting and delivery processes and for quality control plus tracking of letters. RFID does not require a line of sight for information transfer, so it allows postal items to be routed without concerns over item orientation. Multiple items can be read as they pass through the reading field.

H. Container tracing

[15]The transportation of a container does not only involve just one company. Containerized transport involves a large number of handoffs and complex interactions between the manufacturer, shipping line, ports, marine vessels, dray operator and other members in the transport chain.

Inter-modal transport is even more complex, as a container moves between rail, sea and land. Furthermore, a container often travels over international lines with different laws regarding transport liability. RFID technology is here used for electronic container tracing that allows for audit trail, so end-users and shippers can know the exact point where the supply chain went awry.

Two key areas where the feature plays a significant role are to ensure the security of the container, and to streamline the supply chain. In addition, the greatest factors in the security area are in lost prevention and terrorism reduction. The two security issues can be addressed simultaneously with RFID electronic cargo seals and improved end-to-end standard security procedures.

I. Airport

Baggage tagging; Many airlines have run RFID trials over the past few years to prove the efficiency of the systems employed in the air transport environment. Tests have shown first-read rates of over 99% with RF tags compared to less than 90% for bar code-only tags.

[13] http://www.rfidjournal.com/article/view/920

[14] http://www.rfidjournal.com/article/view/1088

[15] http://www.ctl.ca/features/transportation/ctl-container.pdf

In some of the biggest airports like Las Vegas[16], RFID UHF tags are now used to track the luggage. The luggage is via the tags send through a central explosive-detection system, and afterwards routed to the appropriate airplane. In case suspected contents are found, the luggage is send to another security-screening station. With the old barcode system 15-30% of the barcodes were not read. That entire luggage used to be hand scanned which was very time consuming.

With the RFID tags, the reading accuracy rate has been 99.5%, which ensure faster handling and less lost luggage. Among other airports that have started using RFID for the luggage handling is: Brussels's Zaventem, Stockholm's Arlanda, Denver International Airport, San Francisco International Airport and Hong Kong International Airport[17].

The U.S has also started to issue RFID passports[18]. The RFID chip will be shielded, so it will not be possible to scan the passport as long as the passport is not open. The passport will store all the data normally written in the passport, together with a photo for biometrical analyses of the passport holder.

J. Aircraft Industry

In 2008 Boeing[19] is going to deliver the first airplanes in a new series called 787 Dream liner. In the fall of 2005 Boeing held a meeting where, the main suppliers for this new aircraft were invited. It is now a mandate from Boeing, that RFID tags must be used on all spare parts for the new aircraft. The tags have to be passive, they shall have a memory capacity of 64-kilobyte, be resistant to changes in pressure, temperature and humidity.

Apart form having a unique identification number, they shall also be able to hold maintenance and inspection data. The tag has not yet been developed, but Boeing has asked the chip and inlay manufacturers to come up with a solution fast.

K. Cars and Vehicles

In the car making industry, RFID is used for different purposes. For anti-theft systems[20], where low frequency tags are implanted in the car key, making sure, that only the key with the right tag can start the car. And also for the assembly line to ensure that the right spare parts are being used.

For toll-collection[21], RFID tags are used in fast lanes, where the car has an active UHF RFID tag placed in the front windshield, and when the car passes the tollbooth, payment are automatically made.

The trucking manufacturing company Volvo is also working with RFID for asset manage-

[16] http://www.rfidjournal.com/article/articleprint/1949/-1/1

[17] http://www.rfidjournal.com/article/articleview/981/1/1/

[18] http://travel.state.gov/passport/eppt/eppt_2498.html

[19] http://www.line56.com/articles/default.asp?articleID=7007&TopicID=2

[20] http://rfid.emmicroelectronic.com/webfiles/Product/RFID/AN/Wireless.pdf

21 www.eleceng.adelaide.edu.au/personal/peter/peter/GENERAL/RFIDPix.doc

ment[22]. This is giving the opportunity to have better control of the components flow in the production. Volvo is also running trials with UHF tags on fuel cells.

L. Libraries and media management

RFID is used in many libraries to automate the issue and return of books, videos and CDs and to give real-time visibility for library inventory. Until recently, books and CDs have been identified using bar coded labels, each of which had to be read individually with a bar code reader. Inventory control and reconciliation has been a time-consuming operation.

With RFID, books and CDs can be checked in and out automatically and inventory control can be automated using scanners on shelves or with their hand-held equipment. The result is a reduction in the need for personnel and a much higher degree of accuracy in inventory management.

M. Animal detection[23]

With increased concern about food safety and the spread of livestock diseases, countries are mandating the identification of individual animals. The electronic tracking of animals, greatly simplifies this process. On the farm, information can be logged for each animal from growth rates and feeding to health stats and breeding. On the move, accurate information is gathered, without handling the animal, to ensure traceability. The scheme is to ensure that meat, and its history, can be traced back to the individual animal. RFID tags are being used to identify millions of livestock animals around the world. With the RFID transponder in an ear tag farm management and data collection can be automated for breeding practices as well as quality and traceability.

RFID improves the tracking of animals both large and small so they can be more quickly located and maintained. Animal tracking is the largest implementation of asset tracking, production control, and retail logistics in the world. From livestock management systems to scientific research, RFID can help farmers, ranchers, conservationists, etc. to locate and evaluate their domesticated and non-domesticated assets. There are companies and national schemes utilizing RFID Systems products to identify and track cattle, sheep and other livestock. By placing a tag on the animal, details can be gathered concerning health information, animal movement, or market eligibility. Still other companies and foundations are using RFID transponders to track wildlife and fish in order to better understand migration and/or spawning patterns. These patterns can then be analyzed in a database to learn more about the habits of the wildlife all around us.

The International Standard for Radio Frequency Identification of Animals ISO 11784 /11785 based on 134.2 kHz technology is most frequent used.

Tagging of rare animals[24]: *"China will tag all of its 163 captive pandas in an effort to better monitor the population and prevent inbreeding, Xinhua news agency has announced. According to an unnamed State Forestry Administration official: "Information about pedigree, age and other basic data will be permanently incorporated into the giant pandas by ways of molecular labelling or hypodermic implantation of sensing chips."*

[22] http://www.elektroniktidningen.se/index.php?option=com_content&task=view&id=18114&Itemid=87 (Swedish)

[23] Texas Instruments - http://www.ti.com

[24] http://www.theregister.co.uk/2005/03/24/china_tags_pandas1/

N. Asset Management - Beer Kegs[25]

TrenStar owns, manages and tracks millions of beer kegs in the UK. They own more than 60 percent - and counting - of the total number of kegs in the UK, where customers with long-term contracts with the company benefit from the mobile asset management solution. Individual brewers can take advantage of a complete solution that includes asset acquisition, asset management, maintenance, logistics services and RFID technology. Carlsberg, Coors U.K. and Scottish & Newcastle are now seeing the results of TrenStar's mobile asset management solution. Between the three, more than 3.5 million kegs have been fitted with RFID tags and are now tracked at 11 different locations. TrenStar is currently responsible for 2.6 million RFID scans per month, which is just over 31 million per year.

O. Other areas and examples

Sporting event; Vasaloppet: The first Sunday of March there is a major ski contest held in Dalarna, Sweden. The name of the race is "Vasaloppet" (the Vasa race) and it is the biggest ski event in the world. 14,000 skiers participate in the main event and including all the side events during the week the number increases to 40,000 skiers. In order to keep track of all the skiers and their results a RFID-system, from Championship, Netherlands, (in cooperation with IBM) is used. Participants are equipped with a RFID transponder, which is mounted on the leg. In total each and every skier pass nine "choke points", including start and finish, during the 90 kilometres of skiing. Each time a "choke point" is passed the transponder communicates with the reader and sends its information. The information is publicized on the internet and it's even possible to access the information via cell phones in form of text messages.

Football World Cup[26]: The 3.2 million tickets for the World Cup in Germany 2006 will each contain an RFID chip. *FT Deutschland* reported that Philips will manufacture the chip, which FIFA hopes will guard them against forgeries and the black market. The first phase of ticket sales - 812,000 tickets - will be through a draw from applications received by 31 March. Each ticket will look like an airline ticket, with the applicant's name on it. Tickets aren't transferable; the applicant will have to attend the game. The small microchip on the ticket contains only access information, but no personal data. It is the first time that RFID tickets have been sold on such a large scale, although the experiment doesn't come cheap. Each RFID chip costs 10 eurocent and with 3.2 million tickets the organisers have to cough up at least € 320.000. However, Philips hopes that after the World Cup RFID ticketing will be more widely accepted and the price may drop.

RFID - 'REST IN PEACE' - a very different example!

Vandalism of graveyards is a sad but common phenomenon in Scandinavia. These actions are typically performed by bored teenagers in the silence of the night. A lack of resources makes it hard for the churches to protect their graveyards.

Now the Danish software developer Lyngsoe Systems has come up with a solution to prevent desecration of the graves. Gravestones as well as valuable artefacts inside the church are tagged with RFID. When someone tries to move a gravestone, a nearby RFID reader triggers an alarm. The same thing happens if someone tries to steal the tagged chandelier inside the church.

The churches are particularly plagued by vandalism, and the available theft prevention measures are inadequate. Some churches have made experiments with video surveillance, but it doesn't really work at night, and the churches do not want their visitors to feel like they're under surveillance. The RFID-based solution doesn't create that feeling. Lyngsoe Systems' solution could ensure that the dead could rest in peace – at a low cost for churches.

Source: http://www.rfidbuzz.com/news/2005/rest_in_peace.html - Picture: http://www.baltzer.nu

[25] http://www.trenstar.com

[26] http://www.theregister.co.uk/2005/04/04/world_cup_rfid/

Expected benefits

To give a brief exemplification of the expected benefits of RFID, different companies, consultants and articles describe a number of benefits derived from initiating RFID solutions.

The presentation is made to give an indication of what can be achieved with RFID.

Table 03 - Expected Benefits

▪ Labour efficiency/savings	▪ Ensuring timely preventative maintenance
▪ Out-Of-Stock Management	▪ Reducing product obsolescence costs
▪ Inventory Management	▪ Tracking and managing spare parts inventory
▪ Receiving shipping accuracy	▪ Facilitating statistical process control
▪ Reduced claims	▪ Enabling lot/batch track and trace
▪ Reduced not saleable items	▪ Ensuring worker safety
▪ Reduced diversion	▪ Reducing returns and warranty claims
▪ Product recall management	▪ Reducing scrap, waste and obsolescence
▪ Better visibility	▪ Better planning and forecasting
▪ Better fulfilments	▪ Better processes in VMI systems related to reordering
▪ Product integrity	▪ Traceability and safety of products for counterfeiting and maintaining copyrights
▪ Increasing capacity utilization and yield	
▪ Reducing cycle time	▪ Better asset management and handling of returnable assets
▪ Increasing labour productivity	
▪ Improving product quality	

Source: A.T. Kearney (2004) & Chappell and Ginsburg et al (2003) & DTI, RFID Centre (2005)

Internet of Things[27]

The vision "the Internet of Things" combines internet, ERP-systems in companies, mobile units so that you more or less can stay connected all the time or at least have the ability if it is convenient for people or companies. Here the RFID technology is one important element to combine or stay connected and many of the above mentioned solutions in different industries are one step in fulfilling that vision.

Although the Internet of Things is a relatively new vision, its enabling technologies have been around for some time, developed in relative isolation from each other. RFID was invented in the middle of the last century and materials using nanotechnology have been on the market for over a decade. The impact of a combination of such technologies cannot be underestimated which we revert to in a later chapter on RFID in future construction.

The report takes a look at the next step in “always on” communications, in which new technologies like radio-frequency identification (RFID) and smart computing promise a world of networked and interconnected devices. Everything from tyres, building equipment to toothbrushes might soon be in communications range, heralding the dawn of a new era; one in which today’s Internet (of data and people) gives way to tomorrow’s Internet of Things. The report is written by a team of analysts from the Strategy and Policy Unit (SPU) of ITU and was specially prepared for the second phase of the Worlds Summit on the Information Society (WSIS), to be held in Tunis, 16-18 November 2005.

[27] http://www.itu.int/osg/spu/publications/internetofthings/InternetofThings_summary.pdf - November 2005 - “*The Internet of Things*” is the seventh in the series of *ITU Internet Reports* under the title “*Challenges to the Network*”.

4. RFID in Construction today

Lessons from Other Industries

As can be seen from the previous chapter automated technology implementation in other industries has been substantial. The transformation to automated production and handling in other industries over the past years has resulted in the development of effective practices for considering automation during product development, design, security and supply chain management. An understanding of the practices of other industries could effectively enhance consideration of automated technologies in the construction industry.

Case 1 - Boeing 787 Dream Liner project

In 2007 the new Boeing 787 Dream Liner will be ready to go airborne. One[28] 787 Dream Liner consists of around 6 million components. Out of these 6 million components a lot need frequently maintenance and/or replacement. Since an aircraft like the 787 is very expensive, it is a goal from the airlines, that the turnaround time in the airport is as fast as possible. Because of this, to reduce inventory, track parts and to avoided counterfeit part, Boeing together with Airbus, have asked their suppliers to use RFID tags on some selected parts.

Boeing[29] has initially identified 1.750 mission critical 787 parts to be identified and tracked with RFID tags. These parts are chosen either because of their costs or because they have the potential for frequently maintenance and/or replacement.

In earlier Boeing models around 51% of the aircraft parts have been supplied from outside parties. In the new 787 more than 80 % of the aircraft will be depend on external trading partners to design and manufacturer major modules and systems. Over 43 key suppliers on three continents design and manufacturer these systems and modules and transport them to Boeing´s Renton, Washington (US) manufacturing facility for final assembly. It is obvious that the parts needed to assemble an aircraft takes up a lot of space, to reduce the parts on stock, Boeing will use RFID technology to trace the parts, and make sure they arrive Just-In-Time.

RFID will enable Boeing's customers to reduce ownership cost associated with managing LRU's[30] and service part inventory. For example, today most of Boeing's LRUs carry barcode identification labels, sometime located on the back of units. If a mechanic needs to check the cockpit to see which one of three computers is needed to bee repaired, he has to get on his back, with a flashlight in one hand and a mirror in the other, to search for the particular serial number in question. RFID will allow him to walk into the cockpit with a handheld RFID reader and locate the computer in question with a couple of clicks. Similar, a worker checking oxygen tanks on an aircraft has to open every bay containing those parts. With the use of RFID tags, the worker can use a RFID reader while standing in a certain zone of the aircraft to "read" the entire inventory for example to identify quantities of life jackets within a specific distance. Not only will the RFID tags make it easier to track and repair aircraft parts, they will also reduce data entry errors and the risk that suspected unapproved parts (witch range from parts that simply have become separated from they documentation to rare truly counterfeit parts) make it into the aircraft.

Comparison to construction industry and expected benefits:

The comparison of Boeing dream liner to the construction industry is evident - a huge number of components, an enormous number of suppliers, high number of complicated and integrated components, large inventory and demand of spacious area in the production process. But here the comparison stops. Aircrafts are often and always build in series, which very rarely is the case for buildings.

Nevertheless many of the expected benefits to be achieved in such a complicated production should also be able to archive likewise in construction and afterwards in maintenance of the buildings.

[28] Intermec Case study "Air Worthy"

[29] http://www.rfidupdate.com/articles/index.php?id=1138

[30] And LRU (line replacement unit) is a component that can be replaced by a mechanic while the aircraft is parked at the passenger terminal.

They are: (1) Direct and automated surveillance maintenance programmes by a 'click' on a PC or PDA, (2) Inventory control, (3) Control of right equipment at right place and (4) Reduction of data entry errors both during 'production' and afterwards in maintenance. Most benefits can more or less be expected to be transferable to a construction site and maintenance of buildings.

One major problem is however obvious compared to development in the aircraft industry or for example in the retail industry. No one seems to take the role of driving new technology (like Boeing and WalMart) through to the benefit of the whole industry, although there are many major players in the construction industry today also from an international point of view. In that respect the construction industry acts local.

Cases and Pilots

The examples from the construction industry today are given in ***appendix I*** and cover cases as well as pilot projects carried out in different parts of construction processes and operations. Some of them have even more functions and show the variety of potential uses for the RFID technology. Most of the solutions are international and have a global perspective. The table below gives an overview of this variety.

Table 05 **Processes related to construction**	**Potential uses of RFID technology** **RFID Applications**
Facilities Management (Service record of plant equipment)	- Facilities management at Frankfurt Airport - Data tagging for maintenance of plant - Service scheduling
Condition record of fixed assets	- Asset management
Warning systems	- System to track people at location (underground services/ power lines)
Goods received	- iTAG - Ellectronic tagging of materials and components - RFID-based nuclear power plat construction technologies
Logistical operations (track/trace)	- Jobsite logistics (mobile RFID) combined with BIM[31] project - RFID more than track trucks to construction site - Tracking large metal pipes - Using RFID to reduce CO2, optimising operations - RFID tracks power tools
Optimising flows and procedures	- Manufacturing of doors - track/trace - Improving rental equipment delivery performance using RFID
Location of plant and equipment	- Asset management - Path-finding RFID asset tracking - RFID more than track trucks to construction site
Performance/condition of plant and equipment	- Facilities management at Frankfurt Airport
Operative ID	- RFID bolt and digital torque wrench - Embedded RFID: Intelligent concrete
Quality control	- Intelligent tag leaks for hydra - RFID-based nuclear power plat construction technologies - RFID improves testing procedures in concrete - RFID bolt and digital torque wrench - E TJEK delivers dynamic quality control
Security/safety (theft prevention - access control)	- Access control to construction sites - Construction companies reduce thefts with proximity access control - Tool Tracker, Bosch's safe & sound tracking system keeps a watchful eye on tools - RFID tracks power tools

[31] BIM - Building information modelling (BIM) integrates all of the geometric model information, the functional requirements and capabilities, and piece behaviour information into a single interrelated description of a building project over its life cycle. It also includes process information dealing with construction schedules and fabrication processes

Priority in the RFID applications seems to be on,

- Access control
- Construction site safety and security
- Tracking and control of bulk materials, plant and equipment

This is also expressed in the latest statement from one of the big ICT solution providers in the market, IBM.

Tracking the latest industry developments

In the construction industry, pilots are underway with RFID-enabled materials at construction sites, as well as RFID for construction access control and security. Individual objects such as tools are being tagged as it is estimated that for every one hundred workers, the financial loss of small tools totals in the tens of thousands of dollars each year.

IBM, May 2006

We will look into one of the cases/pilots in more detail and has taken an example from asset tracking at a construction site as a 'typical' prototype or pilot:

Case 2 - RFID trial for construction industry is a success

ASSET-TRACKING – using RFID at Construction Site

BT has successfully concluded a path-finding radio frequency identification (RFID) asset-tracking trial with the potential to add real value in the construction industry.

The results of the project, which took place on a major London construction site over a period of two months, could radically improve cost-efficiencies and the management of vehicles, tools and equipment on large sites nationwide. The trial is the first of its type in the sector and was prompted by the increasingly urgent need for monitoring the location and condition of construction assets in transit around sites.

The project was undertaken with one of the UK's largest international construction companies and has successfully proven the benefits of an entirely wireless asset tracking system to an industry where expensive assets such as plant are constantly mobile and exposed to intense conditions.

Ross Hall, CEO BT Auto-ID Services, said: "The findings of this trial are highly significant and could lead to a complete transformation in the way the entire construction industry tracks its assets in the future.

"In the past it has proven difficult to track assets around large construction sites. The ever changing environment is hindered further by limited or no access to power or wired communications. By combining advanced wireless technologies with long battery life, we are able to increase asset visibility and reduce installation, integration, and reconfiguration times, leading to faster deployment and redeployment, resulting in reduced operational costs for our customer."

BT was supported by asset-tracking specialist Ox Loc in the project. Based on pioneering global positioning system (GPS) technology for location, global system for mobile communication (GSM) for data communication and ultra long-range active RFID for asset identification and monitoring, the resulting system had a self-contained battery source, which can be installed within 15 minutes and is capable of supporting a range of sensors to control and monitor asset condition.

Keith Dobson, CEO of Ox Loc, said: "Construction companies are continually challenged with ensuring that expensive assets are secure and have maximum utilisation. Construction sites, with their multiple contractors and ever-changing environments, pose multiple risks including theft, misplacement, and unauthorised use of equipment. After the successful demonstration of this trial we are now in discussions to enable roll-out of the solution later in 2006."

Benefits:

- Radical improvement cost-efficiencies of management of vehicles, tools and equipment
- Need for monitoring the location and condition of construction assets in transit around sites.
- Entirely wireless asset tracking system where expensive assets such as plant are constantly mobile and exposed to intense conditions.

- Combination of advanced wireless technologies with long battery life, which increase asset visibility and reduce installation, integration, and reconfiguration times, leading to faster deployment and re-deployment, resulting in reduced operational costs for the customers.
- Pioneering global positioning system (GPS) technology for location, global system for mobile communication (GSM) for data communication and ultra long-range active RFID for asset identification and monitoring, the resulting system had a self-contained battery source, which can be installed within 15 minutes and is capable of supporting a range of sensors to control and monitor asset condition.
- Avoid multiple risks including theft, misplacement, and unauthorised use of equipment.

Much has been written about the value of RFID in tracking tools and keeping them from “disappearing” from construction sites. Yet few construction companies seem to actually use it. This may however be about to change, as RFID appears to assume an important role in the construction industry, which the above example has shown. This pilot/case is dealing with standard components, but the solution is tailored to this site and test.

Another example of intelligent use of RFID in construction is an embedded tag in a building component that in combination with PDA/PC-solution can connect to a website where all mounting instructions, specifications, drawings and even videos are available.

Case 03 Intelligent Solution with Embedded RFID:
Intelligent concrete and Web enabled Instructions

A build in or attach microchips to concrete panels for industrialised building activated at construction site utilises the facility to get connected to databases via the Internet. By means of a PDA/PC with a special reader mounted on the back, the men at the construction site are able to find all information about the panel immediately that means measurements, weight, serial number, production history, exact mounting instruction and maintenance instructions. The Danish company Dalton Betonelementer A/S has tried, for the time being with a single concrete panel, a landing weighing about nine tons for a construction work in Aalborg. In principle all drawings and instructions should be present at the people building. But in practice we know that this is not always what happens. Then quick decisions are often made and not always the right ones. With a PDA/PC available at the construction site the working men are able to look up the answers to all questions.
Lives can be saved, e.g. when things should be lifted correctly with a crane, and mistakes must not occur when the panel is going to be mounted in the building. The panel referred to is stuck in the walls of the building with only four steel pins which are going to be placed very accurate in order to possess the necessary strength. And it is also possible to lower the construction costs. If it is estimated that one third of the working hours are used to find out whether you have received the wrong materials and you hereafter correct the mistakes, you will be able to save a lot of money by introducing RFID identification via the Internet. As a start the concrete panel is equipped with a little, self-adhesive sticker tag and a printed coil that both work as a signalling antenna and which pick up energy for the chip. The information on the sticker is just a number and a web address that contains the whole documentation.

Many more ideas will come through in the years to come. Embedded tags into products and components in combination with remote access to websites where all relevant information are available can save costs, save paperwork, raise levels of safety, reduce the number of errors during the construction process and raise the quality level in general.

Although there are examples within logistics operations in construction very little focus is on operations across the supply chain as is the case in other industries i.e. retail and food. Also no examples are found looking at the life cycle or deconstruction problems although future demands are coming within EU.

Another expected development that might be seen in the future is the integration to ERP-systems and especially to different planning tools covering the whole construction process from the drawing board to the actual building processes at construction sites. Historically, computers have been applied to solve very specific problems within the architecture, engineering and construction (AEC) industry, leading to a fragmented environment that has been referred to as 'islands of automation' or 'islands of information'. In the future trends

in the areas of computer tools information technologies and integration may provide a common technological platform that unites all areas of AEC computing. RFID technology as carrier of information could be an enabler in the future for seamless integration of processes in construction industry.

One of the pilot cases[32] from Finland combines a Building Information Model (BIM) project with the use of RFID technology. The solution in the pilot project has been to identify each key component with an RFID tag and to read those in several points of the supply chain by using mobile phone RFID readers. In this way the entire supply chain (design, manufacturing, and transportation, reception on jobsite, installation and acceptance) of the selected items can be tracked and traced in real time. And with this status information the model also shows in real time how the building erects! The chosen items to be tracked in the pilot have been project specific items (1) pre-fabricated concrete elements and (2) windows.

The inspiration from the automobile industry is here obvious. In this industry the process from design to production of cars and vehicles has been computerised for a number of years and information management using barcodes and product-ID technologies been part of a normal standardised way of processing.

It goes without saying that the RFID technology offers a great potential also for construction industry, but one major challenge will be dealing with ICT infrastructural problems/solutions. A challenge that both the automobile and the aircraft industry have been working on for many years, but the construction industry just has started to look into the recent year or two.

Many solutions are pilots and are not presently accepted as the normal accepted 'standard' way of performing in construction but have rather the characteristics of trying/using the technology to solve present specific and urgent problems generally - the drivers are not the construction industry itself, but often some vendors and solution providers looking for market opportunities.

Status on development in the four countries in short:

Denmark

Very few examples of RFID-applications in construction industry. The few are in production and quality control and are basically used in production management and not available for customers or user of the products.

Expertise and applications	Company
▪ 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

Finland

Some examples of RFID-applications within access control, tracking, logistics, inventory management and management of defects. Some solutions are international orientated and some have participations of

[32] http://www.enterprixe.com/

large international players (Skanska, Nokia, TeliaSonera). Basically most of them are pilots and small scale demonstrations.

Expertise and applications	Company
▪ 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 Building Information Model (BIM)	▪ Nokia and TeliaSonera - solution provider - pilot presented at SKANSKA

Sweden

Not many examples of RFID-applications running. Some in production and some access and tools management. Vendors of RFID technology and small innovative companies with RFID-solutions try to evoke the industry showing the possibilities in limited areas of construction site.

Expertise and applications	Company
▪ 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

A larger number of cases, pilots and try-outs with different RFID-solutions in all areas - rental management, facilities management, embedded indicators in products, asset tracking and access control, security and service scheduling. Most solutions are initiated by technology vendors trying to solve specific problems.

Expertise and applications	Company
▪ Electronic tagging of materials and components - iTAG	▪ Bovis Lend Lease Ltd.- contractor
▪ Data tagging for maintenance of plant	▪ Bovis Lend Lease Ltd. - contractor at 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 a division of Hydratight Sweeney, part of the Dover Corporation together 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.

Research projects

In one of the earliest research papers to be found on RFID in Construction it says in the conclusion:

"RFID technology is a promising technology for the construction industry that can be integrated into systems that can track materials, identify vehicles, and assist with cost controls.[33]"

This was in 1995 said at a conference and in the meantime and especially in the last 2-3 years development of the RFID technology has escalated in industries with a huge potential in logistics and supply chain management. A similar development in construction industry is still waiting to be seen.

A number of research projects have taken place and research papers have been written all of which more or less conclude the same that the potential for the industry using RFID is very big. There are a number of barriers to break and challenges to meet, so therefore research and innovations are needed to overcome these in the future.

The research papers are given in examples in ***appendix II*** covering the following areas:

Table 06 **Research areas**	**Research title or fields of study**
Supply Chain Management and Logistics - efficiency	- Mobile construction RFID-based supply chain management portal system - Opportunities in improving productivity by developing logistics management and systems - Possible use of RFID technology in support of construction logistics - Integrating bar coding and RFID to automate data collection form construction sites - Improving construction-related manufactured products' supply chain by electronic tagging and tracking using wireless and web technologies
Product ID - using the right component and device	- RFID and TETRA[34] in pumps and pump systems
Tracking and tracing of components, vehicles, parcels etc.	- Field trials of GPS technology for locating material in laydown yards - Field trials for RFID technology for tracking fabricated pipe - phase I and II - Materials and asset tracking using RFID: a preparatory field pilot study - Electronic tagging of construction products and tracking with WAP and Web technologies - Automated part tracking on the construction job site
Maintenance of service systems - Quality control	- Smart Infrastructure - An on-site inspection support system using RFID tags and personal digital assistants - Using tagging and wireless technologies for asset maintenance - Lessons learned from using sensing technologies for active project quality control
Inventory Management	- The use of smart chip technology in the electrical contracting industry - Tool management in construction: an initial comparison of accuracy and scan times for RFID and bar code systems
Track recording of components and materials handling	- Field study of concrete maturity methods in very cold weather - Field tests of RFID technology for construction tool management - The use of the concrete maturity method in the construction of industrial facilities: a case study - Scoping study to evaluate the use of wireless sensors and data acquisition systems for cement, smart concrete and concrete products - Embedded technology in Construction

[33] 'Radio-Frequency Identification Applications in Construction Industry' - Edward J. Jaselskis et al. - Journal of Construction Engineering and Management, June 1995

[34] Terrestrial Trunked Radio (TETRA) is an open digital standard defined by the European Telecommunications Standard Institute (ETSI).

Table 06 Research areas	Research title or fields of study
Deconstruction of equipment - lifecycle	- Utilization of RFID tags for accessing a construction material's history for environmental assessment - ETEK - RFID in recycling data management of electric and electronic equipment - Product lifecycle management and information tracking using smart embedded systems - Using transponder technology to support the end-of-life phase in product life cycle management - Closing the product lifecycle information loops
General or counting more areas	- RFID technology in construction industry - RFID tagging: Applications for the construction industry - Radio Frequency Identification (RFID) Technology and its applications in the commercial construction industry - Radio-Frequency Identification Applications in construction industry (early paper 1995 - looking at possibilities) - Implementing Radio Frequency Identification in the construction process - More profitable business using RFID, wireless and related technologies - Smart tagging in construction - Electronic tagging technologies in the construction industry - Architecture for discrete construction component tracking (basics for standardisation)

Very little interest if any at all is given the latest topics in construction Lean Management - and the influence RFID could have in the process of getting 'Lean'. No doubt however that RFID could be one tool for the industry in getting 'lean'.

Deconstruction of equipment/buildings and life-cycle issues are of current interest due to existing and coming regulations both in EU and national. One research project from Finland (see abstract in appendix II page 76) has been looking into that aspect based on the WEEE[35] directive and use of RFID. They conclude,

"The most important advantages of RFID technology identified in the project include product identification and association with the producer in any phase of the waste treatment process, precise distribution of costs among producers, the possibility for automatic sorting of products, availability of product information, improved efficiency of material flows, automation and improved efficiency of information management, and improved efficiency of collection container management."

Another research paper from Switzerland[36] - " When Waste Becomes Intelligent" - is not convinced that the timing is right just now for utilising the benefits with RFID, saying,

"Concerning durables the potential and the usefulness is likely to be much higher. If the restrictions of producing homogenized information within different industries and the problem with the increasing speed of technological obsolescence could be overcome, a link between production, i.e. design and waste management could be created which would allow for a reuse of the raw materials after use of the goods. Here the tags provide the basic information as to which raw materials can be found in which part of the good to be recycled."

Topics from other industries are safety, counterfeiting, fraud and theft; these are not yet found as research topics within construction industry. However that safety, security, etc. is important also in construction can be seen from the number of RFID cases and pilot projects mentioned in the previous chapter. The question is of course how RFID technology could influence here.

[35] WEEE - "Waste Electrical and Electronic Equipment" EU directive 2002/96/EC (WEEE)

[36] When Waste Becomes Intelligent: Assessing the Environmental Impact of Microchip Tagging, Claudia Binder, Svetlana Domnitcheva, ETH Zurich, CH-8092 Zurich, Switzerland, 2004 - the paper is not included in appendix II as it is not specific related to construction.

To illustrate and point out benefits, barriers and challenges for the industry we have focused on one of the research papers and will look more deeply into this.

Case 4 - Radio Frequency Identification (RFID) Technology and its[37] Applications in the Commercial Construction Industry

RFID in Commercial Construction

RFID has a place in commercial construction because it provides the industry a potential to improve construction productivity, quality, safety, and economy, cutting labour and material costs and enhancing project schedules. Contractors are interested in discovering ways that RFID can save time to provide more efficient project management.

However, do not look for RFID technologies to be implemented industry-wide in the near future. Current risks and challenges associated with developing RFID technologies pose obstacles to strong growth and implementation of RFID. However, several companies and development groups are using pilot studies to identify viable construction applications in determining the economic potential and risks associated with emerging technologies. The construction industry as a whole must collaborate to fully realize the potential for new technologies. The industry should feel obligated to freely communicate and publicize the results of their studies in RFID to lower the burden of cost on individuals, to establish an industry standard, and to minimize risks.

Conclusion and recommendation

- Despite the growing RFID market, the construction industry has yet to adopt methods of construction that utilizes RFID technologies on the jobsite. Lack of standardization, high costs of implementation, slow technology development and deployment risks, and the elimination of unskilled labour are all contributors currently preventing the adoption of new RFID technologies in the construction industry.
- Pilot studies have proven that RFID is an effective method of reducing project activity times and saving project costs. However, project owners and construction managers have not yet comprehended the benefits of using RFID. As RFID technologies develop the cost of RFID equipment and software will continue to become more affordable to all industry users. Just in the last four years the price of RFID tags has shrunk by 75%. Besides, RFID systems require no maintenance and can be used repeatedly.
- The benefit that RFID offers the commercial construction industry far outweighs the initial start-up costs, the costs associated with training and implementation of RFID on the worksite. RFID can benefit the construction industry with applications in materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations, and construction safety. In fact, pilot tests have shown that complete ROI can be recovered in a matter of months. There is also data to support an estimated 3-5% reduction in costs with the use of RFID (Kay, 2003). Contractors need to understand and take advantage of the time savings and lower rework costs that RFID systems ensure. Pilot studies in construction have also illustrated that workers are interested in the new technology and are not concerned that their job functions will be one day replaced by automation. Furthermore, the complexity of construction projects makes it impossible to have completely automated construction; however construction processes and methods that implement the use of automation have the potential to complete projects more efficiently.
- Future case studies and project RFID sampling are needed to increase contractor and owner awareness of the potential savings of human life, project-scheduling times, and project costs. However, the construction industry must be the collaborative driving force behind the development of construction RFID technologies. The industry as a whole must determine today where RFID is applicable so that together they can overcome current limitations and produce transponders with greater read ranges, systems with cheaper implementation costs, and tags with increased durability in the future. Business proprietorship is a major issue in construction; therefore, one must be willing to sacrifice an initial investment to reap the potential benefits of RFID. Further testing of RFID in construction will make contractors and owners more familiar with their applications and with familiarity comes adventure. Once contractors start adventuring into the potential that RFID has, the greater the construction industry will benefit.

[37] Mike Schneider, University of Kentucky, Civil Engineering Department, Master's of Science in Civil Engineering, April 24, 2003

The above research paper has been chosen because it although some 2-3 years old in a splendid way demonstrates benefits of RFID, barriers and challenges for construction industry. Even the recommendations in the research paper could be taken out, updated and proposed again.

So what are the barriers and challenges for the industry?

- Industry fragmentation, slow technology deployment, complex supply chains, high cost of individual research and development, cost of overall RFID packages, and proprietor business concerns are the leading factors affecting the implementation of RFID applications in the field of construction.
- Business proprietorship is a major issue in construction.
- Complexity of construction projects makes it impossible to have completely automated construction.

More technical barriers and challenges would be,

- To overcome current limitations (shortage, frequency, readability) and produce transponders with greater read ranges, systems with cheaper implementation costs, and tags with increased durability in the future.
- To deal with ICT infrastructures in an industrial environment with very little tradition for standardisation.

We will revert to these experiences and statements in a later chapter when RFID in future construction is discussed.

Status on research in the four countries in short:

Denmark

Very little research in RFID in construction industry. A recent published research paper on embedded technology in construction is the only one direct related to RFID. In the Danish construction industry much focus has been on using project webs as a tool to increase information sharing and support collaborative work between team members in construction projects.

Five main topics are central for ICT research in Denmark: (1) Process modelling, (2) Product modelling, (3) 3D-CAD, (4) Project management, (5) Collaborative work (CSCW).

Expertise and Knowledge	Research Institution
▪ Embedded technology in construction - potential savings in construction for public building ▪ *RFID research, other industries than construction*	▪ Danish Building Research Institute (SBI) ▪ *Danish Technical University, Aalborg University, Copenhagen Business School, Danish Technological Institute*

Finland

Number of research projects on RFID is very little. Some have just recently started to look into RFID in relation to construction although there has actually been a tag and responder production in Finland for a number of years. A recent study relates RFID to recycling data management of electrics and electronic equipment based on newest EU-regulations.

Expertise and Knowledge	Research Institution
▪ Research in Logistics management and systems supported by 3D/4D product models.	▪ The Confederation of Finnish Construction Industries RT
▪ Recycling processes and applications of RFID technology related to electric and electronic equipment.	▪ VTT Technical Research Centre
▪ Research on RFID technology in construction - pilots related to wireless and mobile information management - roadmap for implementation	▪ VTT Technical Research Centre

Sweden

No research projects have been found related to RFID in construction.

Expertise and Knowledge	Research Institution
▪ *RFID research. other industries than construction*	▪ *Lund University, Chalmers University (Gothenburg), Linköping University, Mid-Sweden University (Sundsvall), Royal Institute of Technology (Stockholm)*

UK

There are a number of institutions and universities in UK researching in construction. Therefore a larger number of research projects and papers related to RFID, e-tagging, sensors in construction are available. Research papers cover a wide variety of interests within the industry and all parts of the industry.

Expertise and Knowledge	Research Institution
▪ Improving construction-related manufactured products' supply chain.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Demonstration projects - improving construction-related supply chain by electronic tagging.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Electronic tagging of construction products and tacking - web and WAP technologies.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Tagging and wireless technologies for asset maintenance.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Use of wireless sensors for cement, smart concrete and concrete products.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Profitable business using RFID, wireless etc. - state-of-art review.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Wireless and electronic tagging technologies in the construction industry.	▪ University of Salford, Salford, Greater Manchester
▪ Smart infrastructure - wireless sensor network for condition assessment and monitoring of old pipelines.	▪ University of Cambridge, UK (and MIT Boston, USA)
▪ Product ID and RFID technology to pump-manufacturers and pump-users.	▪ British Pump Manufacturers Association (BPMA), Birmingham

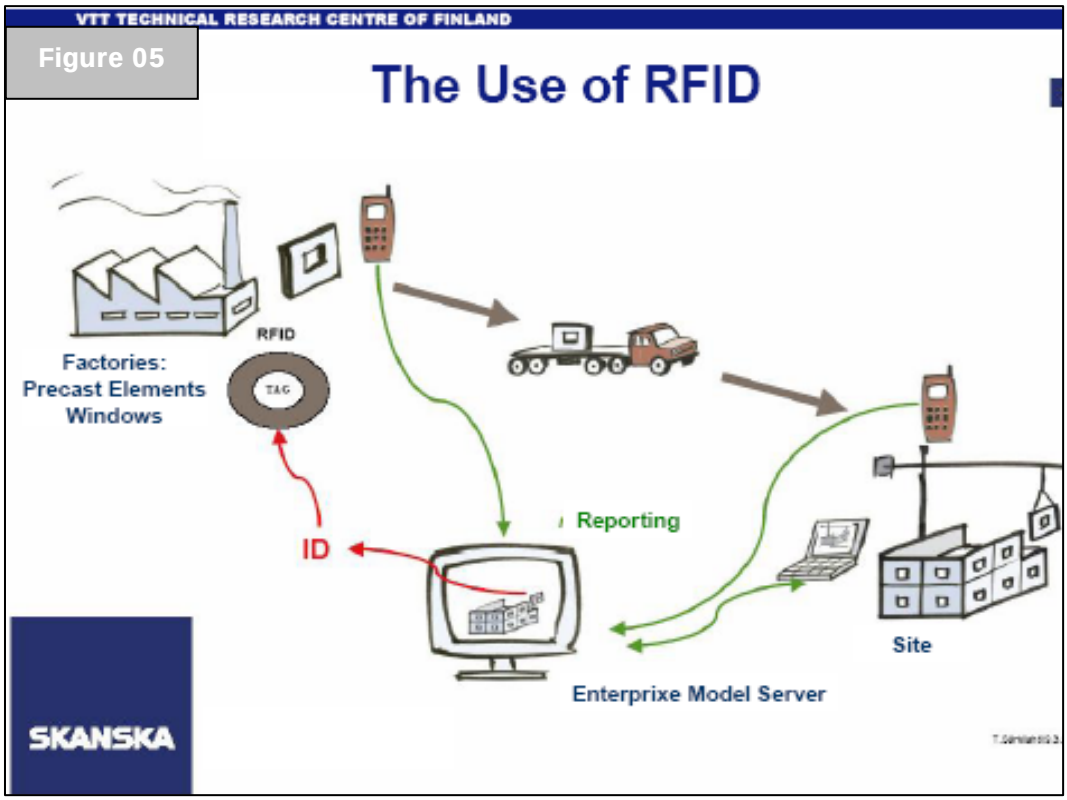
In more general terms some more broader research themes where RFID is not specifically mentioned are given (but not included in research papers in this report) under the heading 'Digital Construction Solutions' - an example of this is the Danish initiative 'Digital Construction' initiated in 2003 setting up the following vision;

Vision: *The end goal is the digital integration of the whole process from the conception of the idea to the finished project. This means that all data are digital and that all agents can work rationally and understand the processes involved.*

Among the aims in this research project it says: "Digital Construction primarily focuses on learning and on the implementation of already available and useable technology rather than on developing new technical solutions. However, this makes it necessary that the technology can be used tomorrow and the day after tomorrow. That is just as important as applying it today. It is therefore essential to have visionary bearings for fully integrated ICT processes that the initiatives can use for directions."

Although RFID is not specifically mentioned this might be some of the means to achieve the vision in the project to facilitate the integration of ICT in processes within construction industry. There are similar initiatives in other countries - more or less worldwide. Specific on visions for ICT in construction is a finished EU-project 'ROADCON' - Construction ICT Roadmap - where VTT, Finland was project leader[38].

Using RFID technology as enabler for handling and managing information in relation to integration into ERP systems and for BIM systems would be seen as an obvious future development which is illustrated[39] in the figure below. A development that would need R&D activities also in fields not directly related to the RFID technology itself but rather to issues within automation and digitalisation in the construction industry.



[38] Construction ICT Roadmap - ROADCON: IST -2001 - 37278 - http://cic.vtt.fi/projects/roadcon/docs/roadcon_d52.pdf

[39] Illustration from VBE/BIM Status Overview - Professor Arto Kiviniemi, VTT Technical Research Centre, Finland, May 2006

5. Driving forces for RFID

As it can be seen in the previous two chapters there are many driving forces for the RFID-technology. One could say that before a group of international retailers with the American WalMart in front put efforts into developing open standards and funded large R&D projects (Auto-ID centre) there was no interest in the technology.

This is definitely not true as many of the examples on the previous pages also document. However the constant push from the big actors in supply chains has brought development forward to a situation where even small companies in a few years will be able to afford and benefit from the technology.

Looking at the driving forces (most important mentioned first) in the different sectors that has been mentioned previously,

√	Retail	**Efficiency**, logistics, asset management, inventory control
√	Food	**Safety**, quality control, tracking/tracing, logistics
√	US DoD	**Security,** tracking/tracing, efficiency, asset management, logistics
√	Pharmaceuticals	**Authentication**, counterfeiting, theft, inventory control, efficiency, quality control
√	Healthcare	**Identification**, asset management, security
√	Garments - Apparel	**Authentication,** counterfeiting, theft, inventory control
√	Parcels and postal services	**Tracking/tracing**, efficiency, quality control
√	Container tracing	**Tracking/tracing**, efficiency, asset management
√	Airports	**Security,** efficiency
√	Aircrafts	**Product-ID,** maintenance, inspections, quality control
√	Cars and vehicles	**Product-ID,** maintenance, asset management, anti-theft
√	Libraries	**Inventory control**, efficiency, services
√	Animals	**Food safety**, tracking/tracing
√	Beer Kegs	**Asset management**, maintenance, inventory control, efficiency
√	Sporting events	**Identification,** security, services

There are many similarities in the different industries and going through them a common theme is the economics - behinds words like efficiency and logistics lies often cost savings. But security, safety, theft and counterfeiting are all also very important driving forces for RFID implementations.

One major push for technology has often seen to be governmental regulations and demands from authorities and this is also the case for RFID - food safety and security regulations are examples of this. Waste and environmental regulations may also be a driver in the future, but this will probably need an even wider spread of RFID technology into more industries and item level tagging of consumer goods and building materials.

Looking at the driving forces (underlined) mentioned for the construction industry earlier,

- Supply Chain Management and Logistics - effectiveness/efficiency
- Lean - thinking - efficiency in operations
- Tracking and tracing of components, vehicles, parcels etc.
- Inventory management and control
- Product ID - using the right component and device - quality and safety

- Precise and exact delivery control - PoD (Proof of Delivery) at job site - quality
- Track recording of certain vulnerable components - windows etc. - quality
- Maintenance of service systems - for equipment, plant, distribution system, fire alarm system, etc.
- Deconstruction of equipment - for safety and right disposal of waste.
- Counterfeiting, fraud and theft - a well known and rising problem

We can see the same pattern in construction industry as in the other industries, but it can be difficult to spot the drivers for the construction industry like for example WalMart for retail.

One could put the question - who could be the "WalMart" for the construction industry?

The question cannot be answered here and presumably there will be many drivers across the industry.

One driver for the DIY[40]-market will obviously be the American chain 'The Home Depot' who is an active member of EPCglobal and also is an active member of the Global Data Synchronization Network (GDSN) which is the backbone for all supply chain operations in retail to gain efficiencies[41].

Could 'The Home Depot' be the driver for construction industry? I.e. putting pressure on all suppliers to RFID-tag all products? No doubt they will be a driver in USA and via this might be for other markets too when it comes to building materials and equipment.

Also for the construction industry new regulations within deconstruction of buildings are on their way which might push development in the direction of more RFID solutions.

[40] DIY- Do-it-Yourself

[41] www.clickcommerce.com

6. RFID in Future Construction

The sources for looking into the future of RFID in Construction have been,

- **Different articles and research papers -** issued within the last 2-3 years.
- **Interviews and questionnaires** from a number of players representing a wide spectrum of actors in construction industry in Denmark, Sweden, Finland and UK
- **Workshops** with actors in construction as well as researcher involved in this project.

Topic in interviews and workshop has been RFID and the technology related to and impact in construction industry.

Challenges

The nature and structure of the construction industry is an important factor in the consideration of developing, implementing and using ICT in general in construction. Education and training, industry standards, rapid advancements in technologies, and the traditional roles of project team members in the industry all affect the interest and ability of initiating and implementing ICT solutions for construction. Below are some examples of barriers within the construction industry that limit effective consideration of ICT in construction in the design phase as well as recommended practices for its consideration. The construction industry is characterised by various challenges in terms of working practices and solutions affecting implementation and development of RFID solutions. These include the following:

- Fragmentation.
- No dominant actor to enforce ICT solutions.
- Information exchange within any construction project is mainly between others than the client and is not, therefore, contractually controlled.
- All actors are involved in numerous tasks and enterprises at the same time, and also at different sites at the same time.
- The industry is project oriented which means that this influences the incentives, accounting, etc. Any ICT must be deployable and profitable within one project to all/several partners.
- Temporary and often short-term business relationships i.e. enterprise partners may never work together again.
- Frequent changes and advances in the technologies.
- A lack of industry-wide standard design elements.
- Acceptance of doing “failure” and then redoing the work.
- A lack of standards for using ICT in construction process, i.e. to exchange information.

Organisations and individuals participating in construction teams bring their own unique skills, knowledge and resources, which include proprietary and commercial software applications. The ICT solutions employed on construction projects tend to be fixed rather than open, and frequently lack support. They are often relatively expensive particularly for small to medium sized enterprises (SME), and offer only limited growth paths in terms of hardware and software. Furthermore there is often a requirement to organise the enterprise around the adopted technological solution.

These are basically the conditions and challenges the construction industry is facing when it comes to looking at new technologies including RFID technology and is also the background for some of the barriers previously mentioned in chapter 4.

The primary reasons for slow construction industry implementation are summarised here:

- Fragmented market for construction industry applications
- Technical risks unique to construction and facilities operations
- Lack of clear industry consensus as to what applications will be used
- Lack of industry standards both from a national and an international point of view

Expectations to RFID in Construction

In E-Core Strategy for Construction RTD from May 2005 it says about RFID in Construction[42]:

"Advances in information and communications technologies (ICT) will result in 'intelligent products', capable of communicating location, orientation and condition. RFID chips represent the first generation of cheap communication devices which can be incorporated in any product. The continued decline in the cost of communications and data processing will enable the built environment to be more intelligent and responsive, and therefore better able to meet the challenges of sustainability and the changing needs of European society."

In this respect the strategy is focusing on:

- more control of systems (heating, ventilation and air-conditioning),
- systems that anticipate and respond to users' needs,
- more effective security systems, with 'central locking' a standard feature in housing,
- continuous monitoring of structures and service systems, with stresses, corrosion, and mechanical performance analysed and automatic diagnoses and report of faults and deterioration in performance,
- advanced detection of fire, with automatic communications and control of protection systems,
- active response systems in seismic regions,
- in-built sensors and communications systems to support and enhance living, particularly for health monitoring and provision of health-care services.

In the recent published research from the Danish Building Research Institute (SBI) "Embedded technology in Construction" it says[43]:

"In the construction value chain from manufacturer of building materials, distributors, constructors, operators and end-users many advantages can be achieved from embedded technology (RFID). However there are very different demands and needs to performance of technology in the different groups."

The report points out the following,

- In manufacturing processes automation, effectiveness and efficiency is the focus area.
- In distribution effective logistics operations across supply chain is the most important issue. Defect products and wrong use can be detected in time. Figures for potential savings in construction industry are not known, but with reference to other industries it is expected to be in the area of 10 - 30 per cent alone on logistics.
- At construction sites and during the building processes the potential lies in better instructions and 'intelligent' building material 'communicating' direct with the craftsmen (via PDA or PC).

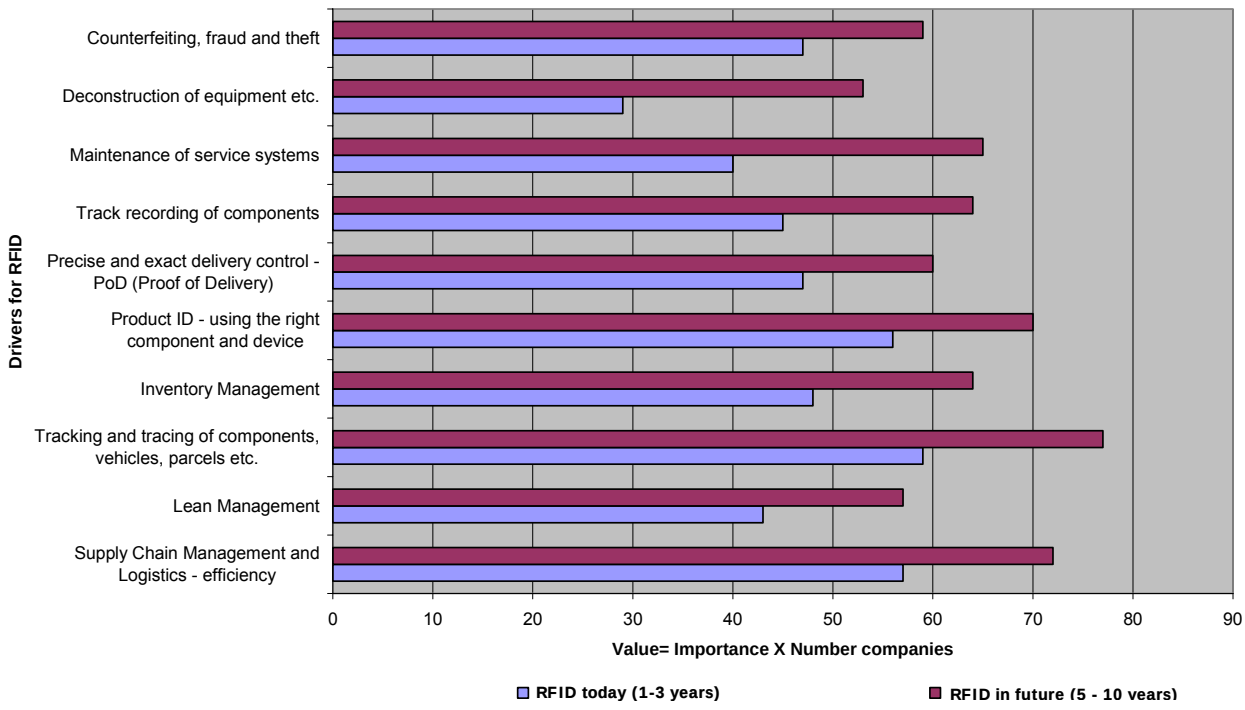
[42] "E-CORE - Strategy for Construction RTD", European Construction Research Network - ECCREDI - May 2005

[43] www.sbi.dk - report in Danish June 2006 - "Embedded technology in Construction" - (potential savings in construction for public building)

- Security, safety and errors in construction are other issues of importance.
- Maintenance, repairs and facilities management are areas demanding further developments and where RFID technology might be the solution to obtain higher efficiency and better performance.

Based on *interviews and questionnaires* from the industry itself and experts[44] the following picture can be drawn;

Figure 06



The chart is a "temperature indicator" for the construction industry and is in no way from a statistical point of view representative. However some indications can be derived from this little research. The different comments from the interviewed persons are listed in Appendix III.

Most important driving forces for RFID in construction are expected to be:

- Tracking and tracing of components, vehicles, parcels etc.
- Supply Chain Management and Logistics - efficiency
- Product ID - using the right component and device
- Maintenance of service systems
- Track recording of components

This is the same both in the short as in the long term except for the power behind the influence.

[44] The interviewed persons represent different parts of construction industry, contractors (6), suppliers (6), consultants and advisors (2), researcher (1), retail (DIY) (1), operators and building owners (4)

From *different articles and research papers* over the last 2-3 years a summery is pictured in the following table 07 - which is based upon observations from a number demonstration projects some of which are also mentioned in the research papers in this report (appendix II).

The observations give a number of operations in construction where RFID will or can influence in a positive way. Here both RFID tags and bar codes are mentioned as technologies that more or less equalise each other.

However one of the research reports in appendix II - ("Integrating Bar Coding and RFID to automate Data Collection from Construction Sites") - concludes that there is a number of advantages in using RFID in automation of operations.

Table 07

How RFID could change the fact of construction

Areas of improvements in the supply chain	Wireless Technology	Tags/ bar codes	Handheld devices	Web application	GPS	Benefits of technology
Tracking manufacturing process in real time	●	●	●	●		More efficient, effective, and profitable processes.
Producing mass bespoke components in the time-scale and cost of mass produced components	●	●	●	●		More efficient, effective and profitable processes. Allow expansion of product range.
Tracking delivery of goods	●	●	●	●	●	Improve traceability of goods and reduce number of disputes on whether goods have been delivered. Eliminate the use of paper based system. Improve customer satisfactions.
Paperless invoicing system	●	●	●	●	●	
Internet visible ordering and delivery service	●	●	●	●		
Asset Management	●	●	●	●	●	More efficient, effective, and profitable processes.
Locating material in the factory and on site	●	●	●		●	Correct goods located and will save man hours in locating goods.
Providing up to date information on site for a tagged building product, e.g. on Health and Safety, installation, etc Enable dispute resolution Demolition/deconstruction	●	●	●	●		This will be possible when bandwidth increases for handheld internet enabled devices. Provide a means to deliver drawings and information required in real time and assist identification and installation of correct parts. Improve information flow in the entire supply chain and aid problem and dispute resolving.
Maintenance of building services and assets	●	●		●		Allow better monitoring of operatives and maintenance scheduling.

Table 07
How RFID could change the fact of construction

Areas of improvements in the supply chain	Wireless Technology	Tags/ bar codes	Handheld devices	Web application	GPS	Benefits of technology
Facilities/ Asset Management	●	●		●	●	Reduce maintenance inspection times. With increased bandwidth wireless technologies to be used to download data required by operatives in real time and improve efficiency, accuracy and reduce number of visits.
Aid in integrating supply chain	●	●		●	●	All the above

Source: Special Briefing, ' Keeping track' - Construction products association - April/May 2004

Summarising this and the previous chapter there are a number of existing and potential applications for RFID in the construction industry.

In the previous mentioned publication "the Internet of Things"[45] the keywords are ubiquitous computing or stay connected at all time combining the three dimensions (1) TIME, (2) PLACE and (3) THING. It says in the report:

"The creation of the Internet of Things will entail the connection of everyday objects and devices to all kinds of networks, e.g. company intranets, peer-to-peer networks and even the global internet. For this reason, its development is of great significance to the telecommunication industry. It will challenge existing structures within established companies, and form the basis for entirely new opportunities and business models. The Internet of Things builds upon the revolutionary success of mobile and internet networks by expanding the world's network of networks even further. It does so through the application of key technological enablers. These enablers have been identified as radio-frequency identification (RFID), wireless sensor technologies, smart technologies and nanotechnology. The 'expanded' internet will be able to detect and monitor changes in the physical status of connected things (through sensors and RFID) in real-time. Developments in miniaturization will further enable technological ubiquity. Networks and the objects they connect are also becoming increasingly intelligent, through developments in "smart technologies"."

Ubiquitous computing calls for object oriented design which is not limited to the construction of virtual objects as solely graphic representations of buildings and their component parts. The emergence of RFID suggests opportunities for linking real world with virtual objects to facilitate design and process management. Effectively, the object oriented approach is a sub-set of the broader paradigm of building information modelling (BIM). The BIM models are accessible to a range of participants including clients, professional disciplines, contractors, facilities managers and building users and is only natural to combine with integration of logistical and maintenance processes in the future construction industry.

Transferring that vision to the construction industry will create a great number of ideas for products embedded with RFID, people at jobsites with direct access to web enabled RFID, distance monitoring of material conditions etc. etc. Some of these developments are mentioned in a few of the presented research papers and one is an actual RFID pilot project. Next step will of course be to look into more details of challenges,

[45] www.itu.int/internetofthings/ - November 2005

barriers, new opportunities and business models for the industry to be able to create new and advanced RFID applications across the industry.

On that basis we will combine our knowledge of the existing RFID-applications, experiences from other industries and research projects and demonstration/pilot projects and try to set up a RFID roadmap for construction industry in the next chapter and discuss the details in relation to challenges and barriers for the industry.

7. R&D on RFID in Construction

The *workshops* previously mentioned have been organised around setting up future conditions for ICT in construction and especially with focus on utilising the RFID technology. Most of the challenges and barriers introducing RFID in construction industry were addressed and is part of the following analysis. As a preparation for this the methodology for the SWOT analysis has been used.

The results from these considerations are pictured in the following. It should of course be taken into account that the strategic tool - SWOT - normally is used for a company or an organisation and not for a whole industry. But is has generally been agreed upon that the findings are representative for the construction industry globally especially when one is looking at technology and especially at RFID.

SWOT

The analysis picture the construction industry with the following - Strengths, Weaknesses, Opportunities and Threats,

Strengths (S)	Weaknesses (W)
▪ Detailed descriptions of all elements in construction ▪ Finding solutions (practical) ▪ Flexibility in organisation/solutions ▪ Information available (often at production/supplier level) ▪ Product knowledge (upstream/production) ▪ Supplier's delivery control ▪ Inventory (real-time) management at jobsites ▪ Product-ID as a tool to link progress of construction tasks and building information model	▪ No 'Right product at right time'- culture ▪ No or little stock control ▪ Lack of qualifications (technology)? ▪ Numbers of products 650.000+ variables ▪ Lack of organised value chain operations ▪ Organisation of construction processes ▪ Lack of communication / mutual understanding among different actors in the processes ▪ Lack of/or missing delivery control ▪ Lack of common and widely used coding system for construction products and materials ▪ Lack of transparency in supply chain ▪ No uniform coding procedures (unique item identifier for construction items) ▪ No standardised processes ▪ Many small companies/subcontractors with low technology implementation level

Opportunities (O) (Using RFID technology)	**Threats (T)** (Using RFID technology)
▪ Customer demands for traceability ▪ Lean Construction tools ▪ Copy protection ▪ Safety/security awareness ▪ Demand for productivity and profitability ▪ Demand for Just-In-Time ▪ Extended use of data (decentralised info) ▪ Speed / visibility ▪ Demand for quality control ▪ 'Intelligent products / processes' - Internet of Things ▪ Facilities management ▪ Improved worksite security/ reduction of shrinkage/theft ▪ Use technology to decrease manual and routine tasks at construction sites ▪ New business opportunities for maintenance services	▪ Missing coherence between digital systems ▪ Missing standardised processes/data handling ▪ Vulnerability for digital failure ▪ Sluggishness form involved parties? (human factor) ▪ Insufficient implementation efforts ▪ International competition. ▪ Development is going too fast? ▪ Resistance of employees against new technology ▪ No feasible business case found ▪ No economical driver found (a "Wal-Mart" for the construction industry) which stimulates the rest of the industry to take up the technology ▪ Further regulations from EU and/or local authorities

We will in the following combine the elements and use the tool - TOWS - analysis or matrix to set up and formulate strategies for R&D on RFID in Construction in a prioritised way.

With information gathered during the workshops, information from the interviews and questionnaires plus previous articles and observations a number of ideas have been selected for development, research and pilot testing to learn more about RFID and its applicability to the construction industry.

However it should be pointed out that although specifically RFID in this report seems to have a great impact and gives benefits to the industry this might probably be the case for other new ICT based technology for automating the industry.

TOWS MATRIX – RFID Technology in Construction

Internal Factors / External Factors	Strengths (S)	Weaknesses (W)
	▪ Detailed descriptions of all elements in construction ▪ Finding solutions (practical) ▪ Flexibility in organisation/solutions ▪ Information available (often at production/supplier level) ▪ Product knowledge (upstream/production) ▪ Supplier's delivery control ▪ Inventory (real-time) management at jobsites ▪ Product-ID as a tool to link progress of construction tasks and building information model	▪ No 'Right product at right time'- culture ▪ No or little stock control ▪ Lack of qualifications (technology)? ▪ Numbers of products 650.000+ variables ▪ Lack of organised value chain operations ▪ Organisation of construction processes ▪ Lack of communication / mutual understanding among different actors in the processes ▪ Lack of/or missing delivery control ▪ Lack of common and widely used coding system for construction products and materials ▪ Lack of transparency in supply chain ▪ No uniform coding procedures (unique item identifier for construction items) ▪ No standardised processes ▪ Many small companies/subcontractors with low technology implementation level
Opportunities (O) (Using new technology) ▪ Customer demands for traceability ▪ Lean Construction tools ▪ Copy protection ▪ Safety/security awareness ▪ Demand for productivity and profitability ▪ Demand for Just-In-Time ▪ Extended use of data (decentralised info) ▪ Speed / visibility ▪ Demand for quality control ▪ 'Intelligent products / processes' - Internet of Things ▪ Facilities management ▪ Improved worksite security/ reduction of shrinkage/theft ▪ Use technology to decrease manual and routine tasks at construction sites ▪ New business opportunities for maintenance services	1 **SO strategy (Using RFID)** ▪ 'Intelligent products / solutions' based on integration among different trades, pre-fabricated elements, and serial production ('IKEA-way')* ▪ Product data, installations guides and maintenance guides available at constructions site or at shelves via mobile units. ▪ Exchange of knowledge across trades, processes, and different projects by using 'intelligent units'. ▪ Automated quality and security checks. ▪ Supply chain management at product and item level.	3 **WO strategy (Using RFID)** ▪ Traceability - technology should ensure 100% traceability throughout SC without human interference. ▪ Batch handling including returning goods/elements. ▪ Tracking on building site optimising logistics, knowing what products are present and available. ▪ JIT - monitoring deliveries, and avoiding congestion. ▪ Research on material - necessary to know what is possible with technology (RFID) on different materials. ▪ Working on standardisation for product coding and information exchange between supply chain partners/ standardisation of processes.
Threats (T) (Using new technology) ▪ Missing coherence between digital systems ▪ Missing standardised processes/data handling ▪ Vulnerability for digital failure ▪ Sluggishness form involved parties? (human factor) ▪ Insufficient implementation efforts ▪ International competition. ▪ Development is going too fast? ▪ Resistance of employees against new technology ▪ No feasible business case found ▪ No economical driver found (a "Wal-Mart" for the construction industry) which stimulates the rest of the industry to take up the technology	2 **ST strategy (Using RFID)** ▪ Education/Information/Marketing - utilising technologies, understanding how it works is just as important as, why it might not work. ▪ Supply chain management - using technology, it has to be spread out through the whole SC. ▪ Standardisation, 'plug-and-play' solutions and standard planning systems to be developed. ▪ Development of "good practice" database and competence centres for RFID in Construction engineering, showing the benefits of the technology ▪ Basics for ROI-calculations	4 **WT strategy (Using RFID)** ▪ Standardisation, 'plug-and-play' solutions and standard planning systems to be developed. ▪ Standardisation and reduction in variation of products - to make lager production series (take example from automobile industry). ▪ Developing more system solutions. ▪ All development activities have to be done by companies. ▪ Training of companies and employees at all levels. ▪ Development of affordable tools for RFID implementation.

The philosophy in using the TOWS Matrix here indicates four strategies, tactics and actions. In practice, of course, some of the strategies may overlap. But for the purpose of description the focus here is on the interactions of four sets of variables. The primary concern here is strategies, but this analysis could also be applied to the development of tactics necessary to implement the strategies, and to more specific actions to support of tactics. In handling of the variables we have prioritised in the following way taking the win-win situations first,

(1) The SO Strategy (maxi-maxi).
- Combining *strengths* in construction industry with *opportunities* should create very important and immediate useful areas for encouragement.

(2) The ST Strategy (maxi-mini).
- Combining *strengths* in construction industry with *threats* should create important areas utilisation for near term encouragements and research.

(3) The WO Strategy (mini--maxi).
- Combining *weaknesses* in construction industry with *opportunities* should create areas for mid time research, encouragements and development.

(4) The WT Strategy (mini-mini).
- Combining *weaknesses* in construction industry with *threats* should create areas for long time research, encouragements and development.

All strategy bullets in the TOWS matrix can be reworded to research or development projects or for some to demonstration projects.

One very important issue for expanding use and knowledge of RFID to the industry is information, education and marketing in all parts of industry and to all levels - mystification of a technology has often been proved to be the worst barrier of all for all technology project implementations. Education (schools and universities), courses (vendors/institutions), training (on site) and workshops (in-/out-company or on site) are some of the keywords in that process. But also building up good practises, industry guidelines (mobile), useful typical practical ROI-calculations (for management) and establishment of knowledge databases are useful tools in this process. Developing scalable show-cases covering all aspects of construction and as a minimum within the most promising areas (including embedded RFID solutions into construction materials) would also be part of the information/education strategy.

These initiatives will be within SO and ST strategies and should be able to be brought into being in the short term.

Important issues are also standardisation processes - standardisation of product coding, information exchange, data integration and data synchronisation. But also development of standardised 'plug and play' solutions (especially for SME's), standardisation of products, systems and processes to maximise benefits for all partners in value- and supply chains. In other industries like the retail, food and automotive industries standardisation and data synchronisation have been topics for many years.

Although very important and with great impact these are also processes that by experience take a long time both at national level and especially at international level.

RFID Roadmap in Construction

In the following we will describe the RFID roadmap from a benefits/value perspective and set the RFID applications in relation to technical/operational barriers for the industry. Present RFID applications are the ones we have described earlier in chapter 4 (table 05) in headings while future RFID applications are potential applications that either have been mentioned in research papers or part of the visions for the industry.

Present RFID applications:

- Production - tracking how far a product has progressed through the production cycle. Tying up an individual product to its current physical location and track when it was manufactured, whether it was received and where it is located.
- Quality control - during production, delivery and construction process.
- Operational control - during production optimising flows and procedures.
- Access control - entrance and whereabouts at construction sites.
- Facilities Management /Maintenance - service record of plant equipment and service scheduling.
- Tracking/trace in rental lots/single items and units/ container / pallet tracking.
- Safety/security control - construction sites and (valuable) item control.
- Asset management - location for assets at construction site or elsewhere.

Some of these applications are pilots, some customised solutions and stand-alone solutions. Although standard components like EPCglobal GEN1 and/or ISO tags may have been used in some of the pilots very few of the applications are standards and off-the-shelves products ready for implementation for the industry. Especially when it comes to integration with other systems at construction sites or into companies' ERP-systems much has to be done in the future to harvest the full benefits.

Future RFID applications:

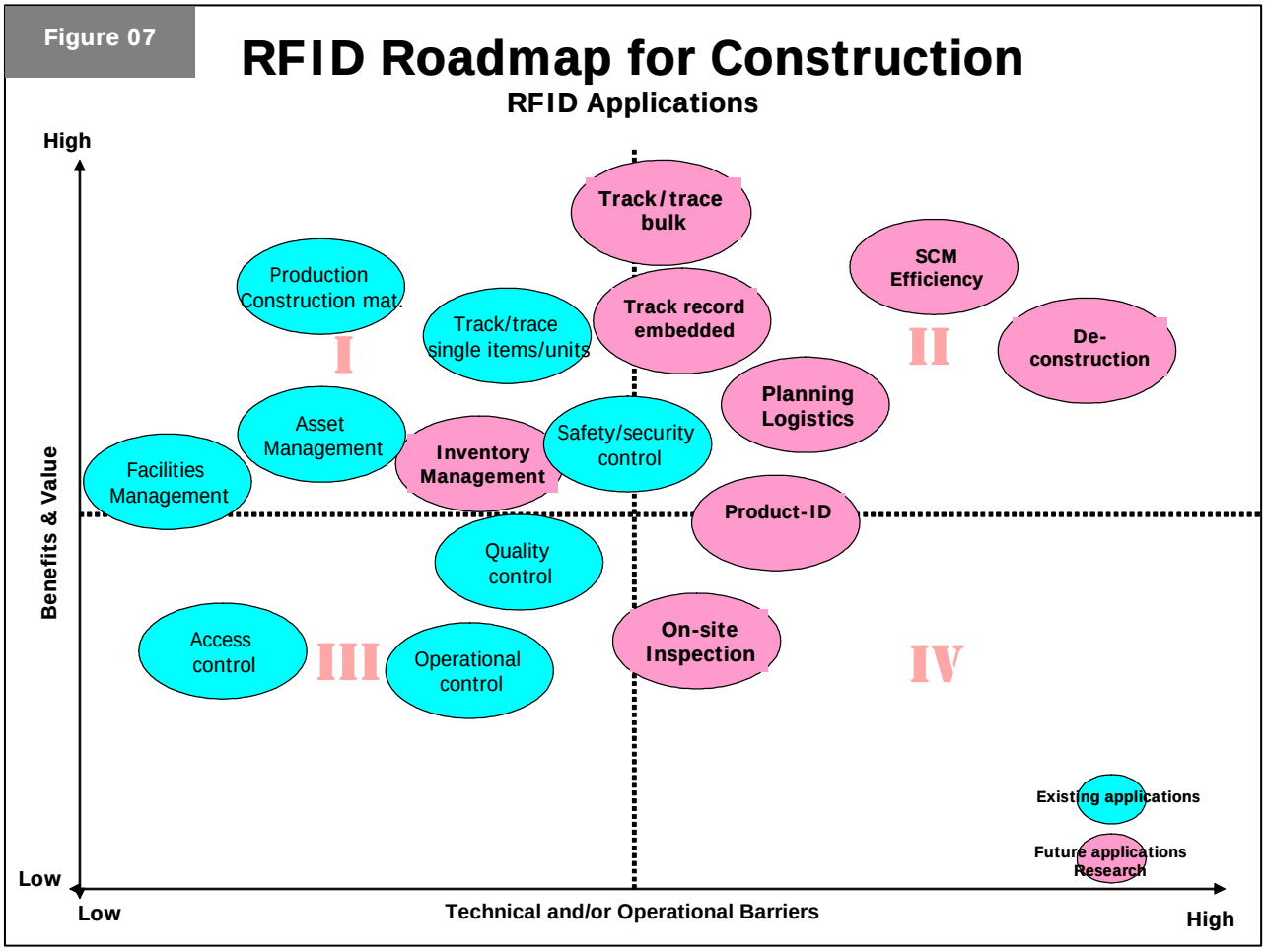
- Inventory Management Control - product inventory, theft detection, point-of-existence verification.
- Supply Chain Management/Logistics- integrated solutions with significant impact on every aspect of supply chain management, including moving goods through loading docks, managing enormous data as information about goods and items on hand collected in real-time.
- Planning Logistics as Just-in-time - proof of delivery, punctuality.
- Tracking - embedded ID tag in products in direct and open connection with surroundings.
- On-site Inspections - right equipment/authority check/quality of processes.
- De-construction and disposals of building materials - fulfilling regulations, managing movements in efficient and secure ways.
- Tracking/trace of bulk product in effective and efficient ways - at construction site, from supplier to the site and returning materials.
- Product - ID - vital products, using the right component and device (Boeing Dream liner example)

In the following matrix we have placed the different RFID applications with a view to benefits/value (high or low) in combination with expected technical/operational barriers (high or low).

Some technical/operational barriers lie on the implementations side (long implementation time or difficult to obtain the skills/knowledge) others due to the structure of the construction industry and complexity (lack of standards, fragmentation etc.)

The different RFID applications are placed in four squares: (I) High value/benefits - Low Barriers, (II) High value/benefits - High barriers, (III) Low value/benefits - Low barriers and (IV) Low value/benefits - High barriers.

Figure 07



From a research and innovation point of view the interesting square is the potential applications for RFID that has the most significant benefits and values for the industry, but also have high technical or operational barriers - (II).

From an implementation point of view all applications within the square high value/low barrier (I) could be accessed and implemented the day tomorrow so to speak. However it is not that simple as no standardised applications exists and the construction industry is very slow in technology deployment (one of the barriers).

Only few of the RFID applications can be said to have reached maturity. Most applications need substantial development and especially for the more integrated solutions also need further research and innovation. The different RFID applications are categorised below in relation to the RFID roadmap in figure 06.

Applications in industrial use (III)

- Access control - different systems are in use. These systems are not necessarily dependent on integration to other systems or standards. Benefits/values are on the controlling side (who is present - at what time and place?); the technical/operational barriers are relatively low.
- Operational control - automation in manufacturing of building material. Different systems to control and monitor production flows. Benefits/values lie on effectiveness in processes; technical/operational barriers

will often be related to integration with existing systems. There is room for improvements and development in integration with other systems and/or other functionalities (i.e. logistics etc.)

- Quality control - manufacturing of building material and control of functionality before integration or use. Systems to control specific performance after production or before application. Benefits/values are cost savings and effectiveness; technical/operational barriers will often be related to backbone integration and access on the distance. There will be room for improvements and development in integration with other systems and/or other functionalities (i.e. safety/security at site etc.)

Ready for take up (I)

- Facilities Management - systems to monitor maintenance processes and service records. Benefit/values lie in time and cost savings; technical/operational barriers are relatively low; if any they will be related to integration with other systems.
- Asset management - systems for managing expensive and large equipments. Benefit/values lie in cost savings and fast turn-around; technical/operational barriers are relatively low could be stand alone solutions, but also integrated with other systems.
- Production - systems for tracking through the production cycle. Benefit/values are often substantial and lie in time and cost savings (waste); technical/operational barriers are relatively low but will be related to integration with other systems. Room for development in integration into other systems.
- Tracking/trace single items and units - systems for individual track/trace often specific customised. Benefit/values lie in cost savings and availability; technical/operational barriers will be related to integration with other systems.

Develop (I/II)

- Inventory Management - no systems available although often mentioned in research papers and necessary for better management at construction sites and warehouses. Benefit/values lie mainly in cost savings (waste) but could also be in time savings; technical/operational barriers are related to integration with other systems. May rather be part of a total integrated supply chain solution?
- Safety/security control - few pilot project solutions. Benefit/values are expected to be relatively high especially in the safety area (work environment) and also rising in security at jobsites; technical / operational barriers will be related to functionality/education.
- Tracking embedded ID tag - few existing systems (only pilots). Benefit/values are expected to be substantial especially in open connection at jobsites and build in functionalities (to be developed further); technical/operational barriers will be related to integration with other systems and functionality/education. Huge potential in development in relation to sensor technology.
- Tracking/trace of bulk products - no systems available presently. Benefit/values are expected to be substantial and lie in cost savings and better management; technical/operational barriers will be related to technical and practical issues related to tag placement and integration.

Research (II)

- Planning Logistics - no systems presently for just-in-time and proof of delivery, punctuality. Benefit / values are expected to lie in time savings and better management; technical/operational barriers will basically be related to integration with systems and data synchronisation.
- Supply Chain Management/Logistics - no present system with integrated solutions in more chains. Benefit/values are expected to be substantial in the whole supply chain; technical/operational barriers will also be substantial and related to standardisation, integration, renewal of procedures and slow technology deployment in the industry.

- Product-ID - no present systems combining ID with functionality (using the right component and device) (Boeing Dream liner example). Benefit/values are expected to lie in performance testing, safety and efficiency; technical/operational barriers will basically be related to control procedures and integration with other systems. Interesting for development of different tests (research area). Will most likely be combined with other operational functionality (logistics, asset management etc.).

Emerging (II/IV)

- On-site Inspections - no present systems for authority check and quality check of processes. Benefit/values are expected to lie in cost saving; technical/operational barriers will basically be related to control procedures from authorities. Will most likely most efficiently be combined with other operational functionality (quality assurance at site, performance testing of equipment etc.).
- De-construction and disposals of building materials - no present systems but a substantial emerging area in the industry. Benefit/values are expected to be substantial for society and will therefore have a very high priority in the future; technical/operational barriers will also be substantial and related to both functional and practical issues. A big challenge will be how existing constructions, buildings and waste handling can be integrated in new applications. Vital topic for research.

The RFID roadmap will also serve as a prioritised list for development, implementation and research in the different areas.

8. Recommendations

The overall question that we have been asking a number of times in this report and also have been discussing among participants in workshops and industry representatives during this project is who can take the driving seat in setting the scene for RFID in Construction?

Recommendation

Change drivers should be the industry itself and public authorities in combination with organisations representing ICT knowledge and development and research institutions world wide. The Auto-ID Labs[46] are an excellent example of what can be achieved at a world class level involving industries.

At this stage in use and development of RFID in Construction we must realise that there are many questions and few answers, most cases that we have been investigating are pilots and not full-scale implementations, many research papers and development projects have caused great interest and many observers but not any steps into fulfilment of RFID strategies.

These trends can also be observed in other industries even in retail and logistics where European companies with few exceptions i.e. the German Metro, seem to be awaiting further innovative RFID solutions (from USA) and still need to be convinced of the performance level of the RFID technology in real-life let alone costs of systems and equipment. In this picture RFID innovation and development today is driven by American companies and institutions and on the RFID technology side also by Asian companies and institutions (China, Singapore, and Taiwan). Europe has some important global players like Philips Semiconductors (tags), Siemens and UPM Raflatac (tags) and Europe has also a strong position in mobile technology which should enable closing the technology gab to US if the RFID development is accelerated.

RFID in construction offers a great deal of potential for industrial innovation and efficiency improvements, but there are still some considerable obstacles to overcome such as[47]:

- Immature application of advanced logistics systems and the absence of information and identification systems in the construction industry.
- Lack of awareness of RFID's potential in the construction industry.
- Low RFID-knowledge and awareness in the construction sector
- Lack of robust RFID-initiatives in the construction industry
- Lack of successful RFID-implementation cases that thoroughly shows its potentials
- The traditionally less industrialised construction industry and its relatively negative attitudes towards new innovations and technology

However, there are several areas where different initiatives can be taken to advance the progress of the RFID development in construction industry.

These are in the areas of:

- RFID best practices
- Education on RFID technology

[46] The Auto-ID Labs are the leading global network of academic research laboratories in the field of networked RFID. The labs comprise seven of the world's most renowned research universities located on four different continents. See: http://www.autoidlabs.org/

[47] See comments in the RFID questionnaire - Appendix III

- Standards for RFID technology
- RFID innovations
- Research on RFID technology

In many instances, these efforts should be joint co-operation by the public and private sectors.

Lessons from other industries will learn the construction industry that some vital areas have to be prioritised. The inspiration from the automobile and aircraft industries are obvious. Here the processes from design to production and maintenance has been computerised and information management using product-ID technologies been part of a normal standardised way of processing for many years. All though these industries are very competitive communications standards, EDI messages, ICT infrastructure and design processes have been developed in mutual co-operation by organisations.

The RFID technology offers a great potential also for the construction industry, but major challenges has to be dealt with both at company level but also at organisational and industry level. Taking the solutions from other industries are more than a 'copy-paste' situation and especially the managing of ICT infrastructural problems/solutions is a huge project that may take many years to overcome.

Recommendation

EU-programmes (7th frame programme), ERA-net programmes, ERA-building programmes and national programmes should be the source to push development in a somewhat reluctant industry. Reluctant to new technology when it comes to knowledge exchange, setting standards, setting up different pilots, benefit from exchange of best practises and cooperate across value chains and supply chains.

The expected benefits to be achieved in complicated productions in other industries should also be able to achieve likewise in construction and afterwards in maintenance of the buildings.

It seems obvious that integration of processes in the supply chains should give the same benefits as seen in other industries and here especially experiences from the retail and food industries, but also by integration of the vertical value chain from design to production and life time maintenance research in BIM and AEC systems promises higher performance and less waste.

We believe that there is an urgent need to provide support and funding to actors, organisations and institutions at a national and European level in order to overcome the obstacles and therefore it is highly recommended to encourage and support specific actions that increase the knowledge of RFID-technology in the construction sector as such.

Recommendation

Governments, national and local authorities are also building owners and employ both direct and indirect many people in construction, repairs and facilities management. Some countries (like the Scandinavian) have a tradition for letting public authorities setting the standards for themselves and the industry will then follow. In other countries (like the UK[48]) the tradition is to form public/private joint ventures in sort of development contracts to push innovation. They could and should take the role of being the RFID driver for own buildings and facilities or go into public/private joint ventures in development consortiums.

- I.e. defining policies and strategies including ICT technologies (RFID included).

[48] Like for example in the chipping of goods initiative - http://www.chippingofgoods.org.uk/

- Setting standards for communication, data exchange, quality control and maintenance (RFID included).
- Developing 'good practise' and show-cases for own buildings and facilities (RFID included)
- Developing training/education programmes for own employees and partners' ditto (RFID included).

Recommendation

Impose legislation (perhaps via EU) on re-use or recycling of building products and on specific hazardous building materials or items where RFID-tagging can be the most cost efficient solution. Could be part of CE-marking setting up a pedigree on each building article/product.
(Like in USA where the FDA announced on 9th of June 2006 that the pharma-pedigree legislation will be introduced as federal law in January 2007 requiring every product to have a pedigree. This can almost only take place by using EPC Global compliant RFID at item level, and this legislation is expected to create a breakthrough for item level tagging).

By acting in this way an often very large building (and facilities) owner or public/private consortiums will set the standards for the whole construction industry and of course be able to harvest the fruits in lower prices and reduced costs.

In some countries digital construction initiatives are already part of a strategy and policy and here it should be very easy to put RFID as an add-on within all relevant areas.

Short term

RFID Best Practices

Looking at what is necessary for RFID to be tried, tested, and evaluated in the construction industry, the primary need is for exchange of knowledge and project RFID sampling to increase contractor and owner awareness of the potential savings.

Recommendation

To prevent the possibility of a fragmented approach to RFID in Europe, the European Commission has set out an ambitious timeline for the adoption of a policy environment that stimulates the use of RFID technology[49]. It is of great importance that the construction industry signs up as stakeholders in this ongoing process where the future policies on RFID in Europe are set.

The ERAbuild organisation should contribute by participating actively in this process involving local governments in stetting up goals and an RFID-strategy also covering the construction industry. Here national involvement by construction companies and organisations is a must.

Recommendation

The main recommendation of this topic is that demonstration projects should be undertaken showing the commercial benefits of using RFID-technology for improving the logistics within the supply chain for a range of construction products (this may also cover the retail site of the industry – DIY[50]). This should be coupled with an effective dissemination and marketing programme which will encourage companies to implement the technology. This could be done by setting up institutions in a joint public/private initiative operated by the industry for benchmarking on RFID projects, demonstrations, exchange of results and practical solutions.

[49] http://www.rfidconsultation.eu/

[50] DIY "Do-It-Yourself"

Recommendation

Next would be setting up or expanding existing RFID-knowledge centres to cover the construction industry including development of scalable show-cases picturing all aspects of construction and as a minimum be able to demonstrate,

- Dynamic quality controls by using 'intelligent units'
- Optimising construction site logistics using 'intelligent units'
- Facilities management with 'intelligent units'
- Managing construction entities on construction sites via mobile units and PDAs
- Managing hazardous waste using RFID (*further legislation will probably be needed*)
- RFID embedded in construction material
  - development of products, showing the feasibility
  - focus into tracking and tracing of project based (mass customized) items: unique building components such as concrete elements, windows,...

Small scale pilot projects have demonstrated utility of employing RFID technology in logistics in other industries. The next logical effort is to expand the study to construction industry and to a larger scale over a longer period of use using RFID-standards (EPCglobal).

A number of countries already have such RFID knowledge and testing centres where an expansion in co-operation with the industry would be a natural development. There is a need for national bodies to initiate pilot projects, generate participation in EU's 7th framework program research into RFID, and especially to disseminate correct and reliable information about RFID technology across the business sectors as well as construction specific.

Recommendation

Therefore a special RFID construction awareness program should be established at the already existing RFID knowledge centres utilising the synergy of a multi industrial benchmarking.

For example like the initiative from England where U.K.'s RFID Centre partners with construction association:

July 20, 2006 - RFID Journal[51]
The U.K.based RFID Centre has formed a strategic partnership with the Construction Industry Computing Association (CICA), an organization dedicated to promoting the use of information technology in the U.K. construction industry. CICA and the RFID Centre have formed a strategic partnership to deliver major benefits for the CICA membership and the construction industry at large. The partnership will serve to raise awareness, provide education and advice about Radio Frequency Identification (RFID) and associated wireless technologies and communicate the extensive benefits and rewards to be gained from deploying these solutions in the construction sector. Together CICA and the RFID Centre are well positioned to inform the industry of the wide range of applications available which include Materials Management, Supply Chain Management, Security, Asset Tracking, Health & Safety and Condition Monitoring and Maintenance. The two organisations are very clearly aligned in terms of a thorough understanding of the application of the technology and well positioned to work together to exploit the technology for the benefit of the industry. The partnership will enable the RFID Centre to communicate the benefits of RFID to the construction industry more effectively and CICA will have an independent, 'credible' RFID technology partner who is able to support and contribute to issues raised by its members and the construction industry generally.

[51] http://www.rfidjournal.com/ and http://www.cica.org.uk/technology/rfid/index.cfm

Recommendation

Suggestion for imposing regulations that might enable RFID technology in building materials and construction processes including the finished buildings. In Denmark alone construction failures and mistakes cost approx. 1.6 billion € per year in changes and rebuilding. This could be avoided if vital parts in the construction process were equipped with a RFID tag and quality of materials and building processes were investigated before delivery to the owner/client. The controlling body could either be imposed voluntarily by the construction industry itself or by legislation (part of planning permission or permit to use).

The controlling body should secure that materials are,

- Built-in correctly
- in good conditions when they where built-in (to avoid leaks)
- kept and handled properly during building process (i.e. to avoid wet gypsum boards and mould)
- transported and handled in a correct manner (to avoid breach)

Although a controlling body like this could be voluntary, local authorities should ensure support from clients, building operators and contractors. RFID embedded in building materials will ease this quality control and reveal any mistakes or failures. The controlling body would also be very good for benchmarking with the manufacturers of building materials for documentation of quality issues.

Usability and education on RFID technology

As RFID technology is implemented in more and more industries and in different environments, there will be a great need for RFID-specific educational efforts at all levels. These include managers, technical staff, and workers in all functions. At the technical level there is presently a shortage of "RFID experts" which is a consequence of the speed and rapid rise of the technology.

Recommendation

Although widely used in many industries the RFID technology is not yet 'off-the-shelves' applications ready to implement easily in any company or industry. The bad news is that RFID implementations need huge efforts in project management even at a minimum compliance level. The good news is that the benefits to the business are substantial, particular if partners from companies' value chains are involved. Despite the size of project a recommendable 4 steps approach would be appropriate,

- Planning
  Activities: Creating a RFID strategy, setting up an application analysis, development of a cost/benefit breakdown, development of implementation model, design of deployment plan, and change management of company processes.
- Physics - certain laws of physics cannot be bypassed (radio waves are affected by liquids and metal)
  Activities: Analysis to understand the environment, product testing for tag selection and placement, selection of hardware and software based on scientific testing.
- Pilot
  Activities: Setting up a small pilot within a limited area (process or business), setup and installation (tags, antennas, readers, portals, hardware and software), testing and redesign (allowing for expansion).
- Production - implementation
  Activities: Managing performance of ICT network, integration of RFID data into existing systems, testing systems with partner in value chains, education of users.

These four steps are appropriate for all industries also for the construction industry. Especially the implementation phase will be time consuming in construction taking into account the many partners, different educational levels and involvement in phases of a construction processes.

Even in small projects these phases should not be underestimated taking into account the challenges the industry is meeting on most technological developments.

Recommendation
For skilled workers there will be a need for retraining in relation to implementation of RFID solutions which we will recommend to be facilitated by existing vocational training centres in cooperation with the industry by developing training programmes and setting up training sites. Also urge large construction companies and industry organisations to build-up on-site training programmes in frequently used RFID-based tools and systems (e.g. gate control, tools management and facilities management).

Recommendation
Vocational training centres should also support basic educational programmes and campaigns in the fundamentals of RFID as a mean to bridge the gap between present technology and the presently low knowledge in the construction sector.

Recommendation
Expanding existing relevant education programmes at universities, industry schools and other training institutions to cover RFID solutions in construction.

Recommendation
Urge organisations and large companies or even fund national or regional technology groups to set up networking groups to benchmark and exchange of information across trades, processes, and different projects within RFID by establishing cross industrial focus groups. (Main issue cultural/trust – establish cross industry focus groups and neutral advisory body) - could be part of an education/training institution integrated with other activities.

Middle term

Standards for RFID technology

One of the factors moving RFID technology and bringing down costs today is the fact that the RFID industry through the extraordinary collaboration of vendors, retailers, manufacturers, governments, and academic institutions is developing a set of standards for RFID technology.

EPCglobal and the International Standards Organization (ISO) are currently the two standards bodies for RFID technology.

Standards for RFID is not enough especially not in logistics operations if the data you are moving is defective. RFID and Global Data Synchronization is part of the same operation as long as you are dealing with logistics. Manufacturers upload the correct, synchronized product data to the Global Data Pool. This makes the data instantly available to all trading partners that have signed on to the Pool. When updates to products and attributes are modified, they can be sent electronically to the data pool and synchronized with the entire trading community. This is the backbone for global retail and trade today and the background for all optimisation of supply chains globally.

Recommendation

Other industries than retail has adopted the EPCglobal standard (Gen1, Gen2 etc.) for example DoD, health-care applications and presently the automobile industry is discussing adoption of EPCglobal.

No doubt the construction industry will be able to benefit from the EPCglobal and ISO standards in many processes of construction especially in logistics operations, inventory and asset management. However other processes such as quality and operational control, facilities management, safety and security will probably need further standards to be developed specifically for the construction industry.

Recommendation

Also standards for product classification need to be standardised on an international (EU or ISO) basis initiated by local/national institutes within construction. A common identification system for construction articles will be a must if the vision of 'Internet of Things' should come through.

Efficiency of the construction process is of major concern to the industry. Indeed significant improvements in this area are necessary before many new technologies like RFID can be taken up and implemented within construction in a cost effective way. Factory production of elements, components and complete building systems (prefabricated panels, walls and other volumetric) is therefore important to the future in the sector in relation to incorporation of RFID-tags or sensors.

Recommendation

This leads to a need for standardisation and reduction in variation of products - to make larger production series (take example from automobile industry). Here EU standard products probably could be developed - plumbing, heating, sanitary, electrical products, etc.? (RFID-embedded or RFID-labelled from the factory).

Long term

RFID innovation

The construction industry is an industry that is very dependent upon paper for transmittals of shop drawings, plans and specifications, change orders and billing, and RFIs (requests for information). Although the Internet has allowed the use of e-mailing documentation there is still a mailed copy sent to other players involved (ACE, owners, etc.). When the costs of RFID technology is more reasonable, applications that embed tags into construction documents, files, or file folders would significantly reduce the amount of time and money spent managing files, and until the industry is paperless there will always be a way to more efficiently manage documents. Therefore the industry has a desperate need for innovation both in materials and in processes including RFID-tagging and embedded RFID.

Recommendation

The main recommendation of this topic is to set up national/regional "Centres of Excellence for RFID in Construction" after inspiration from Finland. The "Centres of Excellence for RFID in Construction" is a partnership between the industry, innovation and educational institutions, and universities. The "Centre of Excellence for RFID in Construction" is a formalized, documented relationship partly funded by local governments with an obligation to produce innovative solutions - building materials containing RFID and RFID applications for the industry, - and exchange best practises between centres in other countries in a network. All parties involved in the "Centre of Excellence for RFID in Construction" will bring to the partnership a special expertise of strategic importance to the construction industry. Typically, the relationship should span anywhere from 3 to 5 years in length, and have the obligation to come up with innovative RFID solutions and also

demonstration projects should be undertaken showing the commercial benefits of using RFID-technology for improving processes in construction.

Recommendation

Push for Innovation in SME's; many companies in the construction industry are SME's that need an extra push to adopt ICT solutions. Therefore special programmes should be set up with focus on SME and RFID,

- Introducing pilots for RFID-implementation in unique and demonstrative cases, and to provide funding to conduct such pilots. Such cases should focus on the efficiency potentials of the RFID-technology and its effects on the construction process e.g. better quality control and increased safety in working environment.
- Development of 'cheap' (low cost) standardised 'plug-and-play' solutions and planning systems for SME's to be integrated in own and/or partner/customer systems including contractors' and building owners'.
- Developing the business case for RFID: exploiting automatic/remote identification throughout business processes in construction covering activities from the drawing boards to the final building.

Research on RFID technology

As we have already seen in the research papers in this report, there will be a great need to conduct academic research on RFID technology for construction to move forward. One of the distinctive characteristics of the development to date of other industries has been the openness of companies and academics to share research and lesson learned and best practise cases. Hopefully, this will also be the case for construction industry when it comes to RFID technology.

For the next 5-10 years or even longer there will be a great need for basic research how to make RFID work in different parts of construction industry and processes related to building materials. Academic work is needed also for practical RFID research (how should tags be incorporated? what can be done to mitigate negative effects from environment? Etc.); however there are very few true RFID experts in universities and few schools that has placed RFID in focus in research. Right now perhaps some of the leading centres in such research areas are housed in MIT, Boston, St. Gallen University, Switzerland, Cambridge University, UK (together started Auto-ID center), University of Arkansas (retail) and Michigan State University (packaging and fruit and vegetables) in the USA. In Europe there are few such centres except the ones already mentioned. Some RFID testing centres have been established for example the RFID Test centre at Danish Technological Institute, who has formed a partnership with two American universities and a RFID test centre at Metro in Germany. More may come in the future.

Recommendation

None of these centres are presently covering construction industry, but a recommendation could be to upgrade one or two of these RFID centres in Europe to also cover construction industry problems and provide funding opportunities for these.

Recommendation

We should also recommend supporting research in order to explore the potentials of the RFID-technology and demonstrate its positive effects on the logistics process in construction industry. This will focus on how RFID has and will affect organisations, both in terms of their internal systems/operations/capabilities and with partnership relationships.

Recommendation

Research should focus not only on supply chain relationships, but also how real-time data can affect performance in buildings, during building processes, maintenance and materials handling for example by utilising the benefits in ERP-systems and in BIM-systems. This should facilitate and fund directed research actions on a national and international level in the specific area of RFID in construction industry.

Setting up a world class research on RFID in vertical integration of construction could be an initiative starting within EU involving the big international oriented construction companies. New and change-oriented actors should be encouraged in order to provide new and less traditional approaches to the construction sector.

Recommendation

Other research topics of great interest to be funded and with great impact would be:

- Industry
  - Research in and development of good practises using RFID, industry guidelines (mobile), useful typical practical ROI-calculations for different areas of construction including focus on those areas that most resemble manufacture – e.g. offsite manufacture for cradle to grave solutions.
  - Research in lifecycle traceability for construction entities including how environmental issues can be managed in a better way by using RFID (utilising ICT systems). Follow the structures status throughout its development and lifecycle. (Whole life-time building model).
  - Research in and focus should be extended to cover more difficult items (bulk construction materials, batch handling including returning goods/elements, etc.) than mass customised low-volume items - how could RFID help to obtain similar benefits or better management?
  - Research on congestion problems at construction sites; can RFID be the solution to develop JIT - monitoring deliveries, and avoiding congestion?
  - Research in how RFID should be used to avoid failures in the construction process.
  - Research on material - necessary to know the possible effects of RFID-technology on products or embedded in different materials in construction.
  - Research in new advanced functionalities in construction materials imposed by RFID-technology to move towards more knowledge-based sustainable products.
- Society
  - Research in Logistics RFID tools to facilitate recycling of building materials.
  - Research in RFID enabled new logistics concepts and manufacturing technologies for full utilisation of construction demolition waste.

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Financing or funding these proposals and recommendations has not been taken into account in this report. Some may be financed locally by institutions, organisations or even governments; some may get the financing via EU funds. Others may find the financing on a pure market basis. However this has not been part of the objective.

Appendix I: RFID cases and pilots in Construction

Summary of expertise and applications:

Expertise and applications	Company
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 Building Information Model (BIM)	▪ Nokia and TeliaSonera - solution provider - pilot presented at SKANSKA
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
	▪ Swedoor, Vest-Wood Group - construction supplier
▪ RFID embedded in doors for production management	
UK	
▪ Electronic tagging of materials and components - iTAG	▪ Bovis Lend Lease Ltd.- contractor
▪ Data tagging for maintenance of plant	▪ Bovis Lend Lease Ltd. - contractor at 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 a division of Hydratight Sweeney, part of the Dover Corporation together 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.
Germany	
▪ Tool tracker - Bosch's safe and sound tracking system	▪ Bosch Group - construction supplier
USA	
▪ RFID tacking of trucks at construction sites - provider of bulk rock and asphalt for construction	▪ The Granite Rock Co., Watsonville, CA - 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 at construction sites using RFID to reduce CO2	▪ Consortium led by Waseda University
Hong Kong	
▪ Testing procedures in concrete improved by RFID	▪ MTR Corporation, Construction
Canada	
▪ Tracking of power tools	▪ Moreau Construction

Detailed descriptions of cases and pilots:

RFID-Case: Access control construction site - Finland[52]

The ELKU access control system is an effective way to control the security of a construction site. It consists of personal identification cards and their casings, readers and necessary information systems. The tag (1 k Mifare 13.56 MHz) is embedded into the casing. The identification card and casing combination includes a photo and name of worker, a name of company and information which sites the worker has accesses to.
At the moment the system is used by 12 construction sites in Finland. Almost 4,000 people have been equipped with identification card now. The system is mainly utilised by major Finnish construction companies.

Objectives:
The access control system based on electronic identification card enables to

- control people moving at a construction site
- give workers a right of access to certain areas
- manage information concerning workers and companies acting at a construction site
- control gates and locks

RFID-Case: System to Track Location - Spain and USA [53]

The Finnish company Ekahau will deploy a RTLS (Real Time Location System) in an underground mine and tunnels in Spain in order to track the underground location of personnel. Ekahau's wireless tracker device for miners is a small battery powered Wi-Fi tag, which features a call button. For the positioning a network of Wi-Fi readers is used, and the Ekahau systems uses the already installed infrastructure.
In case of emergency, the miner can push the call button and the tag will send an alarm as well as its exact location to a remote server which is usually located safely outside of the underground operation. Other staff using wireless computers can access the location information on internal web pages from within the mines by simply pointing their web browsers to an intranet page.

RTLS is also used in hospitals to track patients and valuable assets.

Objectives:
More accurate tracking of personnel and equipment. Decrease of reaction time in case of incidents.

[52] http://www.rakennusteollisuus.fi/rtkoy/Sahkoiset_kulkuluvat_/etusivu (in Finnish only)

[53] http://www.ekahau.fi/?id=20044

Embedded RFID: Intelligent concrete – Dalton - Denmark[54]

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The idea is to build in or attach microchips to concrete panels for industrialised building originates from Innovation Lab, the creativity centre in Aarhus. By means of a PDA (Personal Digital Assistant) with a special reader mounted on the back, the men at the construction site are able to find all information about the panel immediately, that means measurements, weight, serial number, production history, exact mounting instruction and maintenance instructions.
The company Dalton Betonelementer A/S has tried, for the time being with a single concrete panel, a landing weighing about nine tons for a construction work in Aalborg. In principle all drawings and instructions should be present at the people building. But in practice we know that that is not always what happens. Then quick decisions often are made and not always the right ones. With a PDA available at the construction site the working men are able to look up the answers to all questions.
Lives can be saved, e.g. when things should be lifted correctly with a crane, and mistakes must not occur when the panel is going to be mounted in the building. The panel referred to is stuck in the walls of the building with only four steel pins which are going to be placed very accurate in order to possess the necessary strength.
But it is also possible to lower the construction costs. If you estimate that one third of the working hours are used to find out whether you have received the wrong materials and you hereafter correct the mistakes, you will be able to save a lot of money by introducing electronically identification. As a start the concrete panel is equipped with a little, self-adhesive sticker containing a chip and a printed coil that both work as a signalling antenna and which pick up energy for the chip. A RFID. The information on the sticker is just a web address that contains the whole documentation.
The idea of using RFID for concrete panels derives from Innovation Lab in Aarhus.

Objectives:
Advantages of identifying each concrete panel electronically are great regarding handling of documents and the capability of tracking.

RFID-case: E TJEK delivers dynamic quality control to the project 'Pregnant House'[55] - Denmark

A small software-developer company E-Tjek has developed an IT-system that supports online registration of quality-data on the construction site. The system is structured upon construction entities that are associated with a standardised set of control-activities. Each construction entity's quality-data is registered through using a PDA-device on the construction spot.
The company is interested in using RFID-tags built into the construction entities (either by the manufacturer or by themselves) in order to establish a traceable connection between each construction entity and the registered quality-data.
The company has however not applied the necessary technology yet as only a few manufacturers use RFID-tags.

Objectives:
The driver is to establish a lead in the field of quality-systems within the construction industry.

[54] http://www.cadesign.dk/dalton/

[55] http://www.etjek.dk

RFID-case: RFID-Based Facilities Maintenance at Frankfurt Airport - Germany [56]

Service technicians use mobile devices to access daily maintenance plans and carry out work orders. All fire shutters are equipped with RFID tags that store maintenance related information. The technicians identify themselves by scanning their badge and the object by identifying the tag attached to the fire shutter. After performing the checking or the maintenance, the tag is scanned a second time. The transponders have 2 kB of memory, in order to contain all management related information.
The transponders are designed to be attached to metal, and a barcode is added for redundancy. The reading range is only 3 cm, to assure that the technician performs the task. The technology used is 13.56 MHz, ISO 15693.

Objectives:
To improve the performance of maintenance activities. Benefits are better planning, control and documentation of technicians' work as well as improved process quality.

RFID-Pilot: Jobsite Logistics (mobile RFID) - Finland

Skanska Finland had started a Building Information Model (BIM) project, in which they were cooperating with a company called Enterprixe. This software house has developed a 4D "production model" (3D + time) used for construction management on jobsites and which runs on their model server as an Internet ASP service. The beauty of this shared model server approach is that each construction project participant (e.g. architects, designers, builders, contractors and suppliers) can access and work on the same model and can view the always up-to-date information of the building under construction.

Enterprixe's 4D model also includes a supply chain management module for major components and items. This enables the suppliers to enter their production schedules into the model and also to see the status of the target building and each key item. However, the manufacturing and installation status of items were entered basically manually and not in real-time → the status was not timely enough.

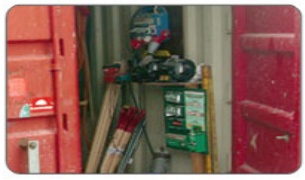
The solution presented by the implementation companies (Nokia Corporation, TeliaSonera) was to identify each key component with an RFID tag and to read those in several points of the supply chain by using mobile phone RFID readers. In this way the entire supply chain (design, manufacturing, and transportation, reception on jobsite, installation and acceptance) of the selected items can be tracked and traced in real time. And with this status information the model also shows in real time how the building erects!

The chosen items to be tracked in the pilot were project specific items:
- Pre-fabricated concrete elements supplied by Taskinen
- Windows manufactured and installed by Fenestra

Objectives:
- To enhance supply chain visibility and transparency throughout all the construction project participants.
- To get better and more accurate information flow between the jobsite and suppliers → more accurate and timely deliveries → right items in right place in right time in right sequence.
- To avoid serious flaws by identifying each item exactly and uniquely → no hassle and extra work with wrong items or with wrong delivery sequences.
- To enhance ability to keep to the project schedule → savings in labor costs throughout the project and avoidance of contractual penalties.
- To reduce buffer inventories, both at factories and on-site.
- To handle management of defect notifications and respective claims easier.

[56] RFID based maintenance at Frankfurt Airport, Pervasive Computing, IEEE, Jan-March 2006, pp. 34-39

RFID-Case: Asset management, access control at Construction site - Sweden[57]



The company Safetool, based in Jönköping, has as a business concept to supply companies in the construction industry with a technical platform and systems for safer keeping and to simplify inventory and localisation of tools and machines. The company has in co-operation with construction companies and machinery rentals created a system for safer construction sites. The technique is based on RFID-technology. A passive RFID-tag is applied on machines, tools and on identity cards and communicates with active tags on lookers and antennas in containers and sheds. With GPRS and TCP/IP the user get access to the information thru a computer connected to the internet. Every year machines and tools to a value of 1.5 billion SEK are stolen from Swedish construction companies. To prevent this several construction firms plan to integrate RFID labels in machines and tools.

The benefit for the costumers is, by Safetool, access control for a safer construction site, containers with day- and night lockers who only can be opened by qualified staff and better utilization of the resources on the site.

Objectives:
A quite small company who combines customers need for safety with technology. In this case the RFID-system only covers the needs for order and safety on the construction site.

RFID-Case: Construction Companies Reduce Thefts with Proximity Access Control - Sweden[58]

TracTechnology is currently installing GateTrac-Construction at one of Skanska's - Sweden's largest construction company – ongoing rebuilding projects in Stockholm city. TracTechnology supplies complete access solutions for construction sites. They install control of entrance and exit gates on site, long-range RFID readers, key tags and contact-less cards with printed text and logos. The web interface of the GateTrac- Construction access control system is installed in a multi-user environment.
GateTrac handles all administration and access control. Each RFID card in the database is connected to a group - e.g. electricity, plumbing, recycling etc. Each cardholder is also connected to his/hers corresponding company. Information is handled centrally through web UI on the corporate network. The construction company gets useful statistics of visits by time interval, gate, individual person, class and company.
TracTechnology also offers GateTrac system versions dedicated to car parking payments and entrance control at recycling plants, campsites and marinas.

Objectives:
A way for a construction company to take control of and reduce accelerating costs is to provide every employee with a proximity key fob for entrance and exit access.

[57] http://www.safetool.se/english/default.asp

[58] http://www.rfidnordic.se/RFID_nr1ENG_06.pdf

RFID-Case: Manufacturing of doors - track/trace - Sweden/Denmark[59]

The door manufacturing company Swedoor (part of Danish Vest-Wood group) with production in Skåne applies a RFID-tag on each and every door. Information about material and processes is stored in a tag and which makes it possible to follow the door thru the whole supply chain. When the door leaves the factory the information in the tag is copied to a database and from that Swedoor can use the information for invoicing, statistic and perhaps reclamation. The tag follows the door out from the factory and can be used both by constructors and later on by care takers of the estates. The technology comes from the American company Escort Memory Systems (EMS) based in Silicon Valley.

Objectives:

The technique offers the opportunity to make every door individual and the information stored in each door makes the invoicing easier. With the information stored within each individual door in the manufacturing the RFID tags can be used continuously throughout the whole supply chain.

RFID-Case: Tool Tracker, Bosch's Safe & Sound Tracking System Keeps a Watchful Eye on Tools[60] - Germany and USA

Jobsite theft has become so rampant that practically every contractor has a tragic tale of having thousands of dollars of tools and equipment stolen from trucks, toolboxes, and jobsites. And while we'd like to think that jobsite theft is always the work of experienced, professional crooks, often it's an inside job. Bosch is aiming to ease some of the industry's theft woes with Safe & Sound, a tool tracking system and theft deterrence tool that utilizes RFID (radio frequency identification) technology to tag and track tools. Construction firms can special order power tools with bar codes that carry unique identification for each tool, including model and serial numbers; rather than attached to the outside of tools where they can be defaced or removed, the tags are imbedded inside. In addition to tool tracking, contractors also can utilize the tagged tools with AcoustoMagnetic jobsite security portals, similar to what you would find in a retail store. Placed at jobsite gates and entryways, the portals sound an alarm when an activated tool passes through.

Objectives:

Companies using the tags can then scan the tools with a mobile scanner and, using a software program such as Toolwatch SE, can keep track of who checks out and returns the items. RFID tags also can be imbedded into tools—of any brand—that the contractor already owns.

RFID-Pilot: iTAG - Electronic Tagging Of Materials And Components[61] - UK

Bovis Lend Lease has trailed electronic tagging of deliveries, using technology normally found in automotive manufacture and retailing. They call their innovation 'iTAG'. iTAG has been tried in two quite different projects. At Safeway in Stratford (a supermarket, library and hotel) were they concentrated on deliveries during construction, while at Calderdale (a PFI hospital) they were looking for benefits in extending the long term maintenance. Bovis Lend Lease state that iTAG will provide access to key product information at every stage of the project.

Objectives:

Improve material management and facilities management. Data tagging provides accurate productivity information, allowing reasons for delays and resource consumption to be recorded, when data has been uploaded into the central maintenance database.

[59] http://www.oeresundsbron.com/object.php?obj=16402afd in Swedish; Swedoor, Vest-Wood Group

[60] http://www.boschtools.com

[61] www.constructingexcellence.org.uk

RFID-Pilot: Data Tagging for Maintenance of Plant[62] - UK (look also above)
At Calderdale hospital, Radio Frequency data tagging has been used to improve the 30-yearmaintenance programme, by replacing the traditional paper systems used for maintenance management, with data tags and hand held computers that record all planned and reactive maintenance. Data tags are fixed to items of plant and machinery and provide immediate access to key information.
Objectives: Improve facilities management.

RFID-Pilot: Improving rental equipment delivery performance using RFID technology[63] - UK
Arnlea Systems, a leading provider of RFID (Radio Frequency Identification) and mobile information solutions, has won a new five figure contract from AMEC Internal Asset Management Limited, the mobile rental equipment company that forms part of the AMEC Group, to deliver an RFID-enabled mobile rental plant and equipment tracking system. The contract follows previous RFID-enabled mobile maintenance solutions delivered by Arnlea to AMEC and recent successful trials by a leading oil and gas company of Arnlea Systemsâ™ proven mobile rental equipment tracking system.
Objectives: Improve management and tracking of rented equipment. By uncovering new information as a result of automating a previous paper-based process, AMEC expects to identify further areas where equipment management processes can be improved to deliver a proactive service to its customers.

RFID-case: RFID tags help ensure integrity of oil[64] - UK
A key element in the construction and maintenance of oil and gas facilities is the integrity of the pipeline joints in pressurised systems. Hydra-Tights bolt tensioning role is to ensure that pipe-work systems are correctly assembled with the correct gasket, bolts and to the correct bolt tension (torque). Incorrect assembly invariably leads to leaks that are costly and can be a serious safety issue, due to the flammable/explosive nature of some of the products routed through the pipe work systems. The use of RFID (Radio Frequency Identification) tags to identify individual pipe-work joints was seen as a unique selling point for Hydra-Tights' services. Previously, identification had been by hand written labels, metal asset labels or reference to drawings. By identifying each joint using autoID technology, a database could be built up to hold information specific to each joint thus ensuring the operatives carried out the correct procedures and used the right parts during a new build or rebuild of pipe work systems.
Objectives: Recording electronically the identification of each joint as it was 'worked', a full traceability system could be set up.

[62] www.itconstructionforum.org.uk

[63] http://rfidtimes.com/

[64] AIM, UK – www.aimuk.org

RFID-Pilot: Path-finding RFID asset tracking [65]- UK

British Telecom's RFID unit launched its first off-the-shelf product, offering customers an active tag system to help track and manage reusable business assets. BT Auto-ID Services, the RFID unit of British Telecom, has launched its first offering, a managed service involving active RFID tags called AssetIntelligence. This service targets companies looking to track and manage their reusable business assets better without investing in or developing their own RFID systems. AssetIntelligence bundles together RFID equipment and tags, system design and deployment and the software and server hardware needed to collect and distribute the data. It uses active RFID tags and readers (interrogators) from BT partner WaveTrend and a BT-hosted version of RedPrairie's mobile Resource Management (MRM) asset management application.

British Telecom has successfully concluded a path-finding radio frequency identification (RFID) asset-tracking trial with the potential to add real value in the construction industry. The results of the project, which took place on a major London construction site over a period of two months, could radically improve cost-efficiencies and the management of vehicles, tools and equipment on large sites nationwide. The trial is the first of its type in the sector and was prompted by the increasingly urgent need for monitoring the location and condition of construction assets in transit around sites.

The project was undertaken with one of the UK's largest international construction companies (Laing O'Rourke) and has successfully proven the benefits of an entirely wireless asset tracking system to an industry where expensive assets such as plant are constantly mobile and exposed to intense conditions.

Objectives:

Construction companies are continually challenged with ensuring that expensive assets are secure and have maximum utilisation. Construction sites, with their multiple contractors and ever-changing environments, pose multiple risks including theft, misplacement, and unauthorised use of equipment.

RFID-Case: Service Scheduling[66] - UK

Byzak required a method of reliably planning and recording the scheduled servicing and maintenance of their plant and machinery. They also needed to produce accurate maintenance certificates before the machinery could be hired out. The solution was to introduce a Planned Preventative Maintenance System using RFID (Radio Frequency Identification) tags that are stuck to the machinery to store information. All maintenance information is available to (and edited by) the service engineers via a handheld Psion and transferred electronically to a planned maintenance database. Payback on investment is estimated to be within one year.

Objectives:

This system automatically matches the service schedules with plant and machinery, in doing so it ensures each machine receives the correct maintenance programme.

[65] http://www.publictechnology.net

[66] http://www.technology-watch.info/pdfs/Byzackpage10.pdf

RFID-Case: RFID More Than Track Trucks to Construction Site[67] - USA

Since the construction company deployed RFID at all its locations, customers have benefited from a wealth of information based on the arrivals and departures of trucks through Graniterock's asphalt and quarry operations.
With more than 3 million pounds of granite, sand and other construction materials being loaded onto 600 trucks per day at the A.R. Wilson Quarry, Graniterock's largest, customers are happy to get as much information as possible.
Graniterock has been able to attain efficiencies by using its business intelligence reporting system in combination with RFID tagging. In fact, the company has been able to reduce by half the amount of time it takes to load customer trucks at its quarries. The RFID project at Graniterock began in 2000.

Objectives:
The RFID system processes the arrival and departure of trucks through the company's asphalt and quarry loading locations. Customers use the reports to determine how quickly a particular construction job is progressing and how efficient their supply chains are.

RFID-Pilot: Tracking large metal pipes[68] - USA

Fluor Construction found that active RFID tags could track large metal pipes stacked on a truck with 100 percent accuracy. An RFID trial was conducted at a pipe fabrication plant in Houston, Tex., to determine whether RFID could help automate the shipment and delivery of key materials from fabrication plants to construction sites.
The three-phase trial was hosted by Fluor Construction, one of the world's largest, publicly owned engineering, procurement, and construction and maintenance companies. Fluor turned to one of its materials fabricators, Shaw Industries, to help deploy the RFID trial at Shaw's plant.

Objectives:
One key goal was to see if the technology could stand up to the rigors of harsh construction industry environments.

RFID-Case: RFID-based Nuclear Power Plant Construction Technologies[69] - Japan

Hitachi announced on (01/2006) that it has developed radio frequency identification (RFID)-based technologies applicable to nuclear power plant construction. Specifically, the company has developed two new systems, an RFID tag system used in the processes of manufacturing and installing pipes, and an RFID-based cable connection navigation system.
The navigation system uses RFID tags attached to both cable cores and end terminals to simplify cable connection work and help workers easily check for errors when they connect cables.

Going forward, Hitachi plans to proceed with research, focusing on the establishment of rules of using RFID tags, the integration of the tags into the existing systems, and the development of basic technologies including metal-compliant antenna. Through these means, Hitachi aims to contribute to the development of next-generation nuclear power plants.

Objectives:
With the RFID tag system, RFID tags are attached to construction materials as they are delivered so they can be efficiently monitored in distribution management. Subsequently, it will lead to preventing human errors and ensuring the traceability of the materials used.

[67] http://www.eweek.com

[68] RFID journal - Jan. 5, 2004

[69] http://www.japancorp.net/Article.Asp?Art_ID=11721

RFID-pilot: RFID improves testing procedures in concrete[70] – Hong Kong

To improve its testing procedure, MTR MA implemented an RFID solution. Using smart labels is already providing benefits in the materials testing process, improving quality control and assurance, and eliminating the problems in the sourcing and tracking of concrete samples. Now, instead of putting a paper label onto each sample after the concrete has set, MTR MA embeds RFID labels onto the top surface of the test blocks while they are still wet. Handheld readers are then used to program the labels with a series of data to identify the origin of the concrete before the samples are sent for testing, and the data from the handheld are uploaded to a server. When the concrete sets the labels cannot be removed without destroying them, thus preventing the blocks from being switched or replaced. During the testing process the test-blocks are subjected to high temperatures, moisture and vibration, so the chips and inlays are encased in durable plastic packages.

Objectives:

RFID-labels allow test data to be captured electronically (with each sample uniquely identified by its serial number), it's much faster to create reports and statistical analyses.

RFID-Case: RFID Bolts and Digital Torque Wrench - Japan[71]

KRD Corporation in the city of Zama (Kanagawa Prefecture) has developed RFID bolts. Using special digital torque wrenches, one can maintain records about each bolt: when it was fastened and how much force was applied while fastening, etc. Potential application areas include airplane assembling factories where lots of parts and bolts are used since RFID bolts may make be used to make sure that all bolts are fastened.

Objectives:

Track recording and assembling quality control

RFID-Pilot: Using RFID to reduce CO2, optimising operations - Japan[72]

A consortium led by a Waseda University professor developed systems that utilize RFID tags to efficiently deliver machinery and material to construction sites, and thereby reduce the amount of carbon dioxide emitted by trucks.
Usually, each construction site directly orders material etc. from manufacturers and the material is individually delivered to each construction site. This can easily cause the situation that many trucks go back and forth between construction sites and manufactures with only a small amount of stuff on board. So, the consortium implemented a delivery network that has a component called Logistic Service (LS). LS is located between manufacturers and construction sites, and allows different construction sites to share the delivery network. In order for the sharing model to work, it is necessary to accurately track the delivery activities in real time. This is where RFID tags play a key role.

Objectives:

The consortium recently finished a pilot test and confirmed that they could reduce by 22% the carbon dioxide emitted from delivery trucks.

[70] AIM, UK – www.aimuk.org

[71] http://www.byz.org

[72] http://www.byz.org

RFID-Pilot: RFID tracks power tools - Canada
A Québec construction firm recently adopted radio frequency identification (RFID) tags to speed up, simplify and streamline tracking of its power tools on job sites. RFID is helping Moreau Construction, in Rouyn-Noranda to better manage its tools inventory worth around one million Canadian dollars. These tools are carried in and out of company premises several times a day by Moreau staff. The problem is common among construction firms - statistics indicate the problem of misplaced or stolen tools is pervasive in the industry. According to the theft-prevention service provider National Equipment Register (NER), construction companies lost up to $1 billion due to misplaced or stolen equipment last year (2005) alone.
Objectives: Tracking tools used by workers at job sites and theft.

Appendix II: Research projects - RFID in Construction

Summary of expertise and knowledge:

Expertise and Knowledge	Research Institution
Finland	
▪ Research in Logistics management and systems supported by 3D/4D product models.	▪ The Confederation of Finnish Construction Industries RT.
▪ Recycling processes and applications of RFID technology related to electric and electronic equipment.	▪ VTT Technical Research Center, Finland
▪ Research on RFID technology in construction - pilots related to wireless and mobile information management - roadmap for implementation	▪ VTT Technical Research Center, Finland
Denmark	
▪ Embedded technology in construction - potential savings in construction for public building	▪ Danish Building Research Institute (SBI)
▪ *RFID research in other industries than construction*	▪ *Danish Technical University, Aalborg University, Copenhagen Business School, Danish Technological Institute*
Sweden	
▪ *RFID research in other industries than construction*	▪ *Lund University, Chalmers University (Gothenburg), Linköping University, Mid-Sweden University (Sundsvall), Royal Institute of Technology (Stockholm)*
UK	
▪ Improving construction-related manufactured products' supply chain.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Demonstration projects - improving construction-related supply chain by electronic tagging.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Electronic tagging of construction products and tacking - web and WAP technologies.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Tagging and wireless technologies for asset maintenance.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Use of wireless sensors for cement, smart concrete and concrete products.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Profitable business using RFID, wireless etc. - state-of-art review.	▪ Building Research Establishment (BRE), Garston, Watford
▪ Wireless and electronic tagging technologies in the construction industry.	▪ University of Salford, Salford, Greater Manchester
▪ Smart infrastructure - wireless sensor network for condition assessment and monitoring of old pipelines.	▪ University of Cambridge, UK (and MIT Boston, USA)
▪ Product ID and RFID technology to pump-manufacturers and pump-users.	▪ British Pump Manufacturers Association (BPMA), Birmingham
EU	
▪ Product lifecycle management and information tracking using embedded systems.	▪ The EU consortium consists of 22 partners from 9 countries - www.promise.no

USA	
▪ Field trials of GPS technology and tagging for locating material.	▪ FIATECH Consortium, Austin, Texas
▪ Materials and asset tracking using RFID - preparatory field pilot study.	▪ FIATECH Consortium, Austin, Texas
▪ Field trials of RFID technology for tracking fabricated pipe.	▪ FIATECH Consortium, Austin, Texas
▪ Concrete maturity methods in cold weather using tags	▪ FIATECH Consortium, Austin, Texas
▪ Concrete maturity methods using smart tags.	▪ FIATECH Consortium, Austin, Texas
▪ RFID technology for construction tool management.	▪ FIATECH Consortium, Austin, Texas
▪ RFID tagging - applications for the construction industry.	▪ CII, based at The University of Texas, Austin
▪ Smart tagging in construction - imbedded in objects	▪ National Institute of Standards and Technology, Gaithersburg, Maryland
▪ Establishing standards to support identification and tracking technologies.	▪ National Institute of Standards and Technology, Gaithersburg, Maryland
▪ Standards for automated part tracking at construction site.	▪ National Institute of Standards and Technology, Gaithersburg, Maryland
▪ Sensing technologies for active project quality control to avoid defects during construction.	▪ Carnegie Mellon University, Pittsburgh
▪ Utilization of RFID tags for accessing a construction material's history.	▪ Carnegie Mellon University, Pittsburgh
▪ RFID technology and applications in commercial construction industry.	▪ University of Kentucky, Lexington
▪ Smart chip technology in electrical contracting industry	▪ University of Kentucky, Lexington
▪ Tools management in construction, comparison between RFID and bar coding.	▪ Texas A&M University, College Station
▪ RFID applications in construction industry.	▪ Iowa State University, Ames
▪ Implementing RFID in construction process	▪ Iowa State University, Ames
▪ Smart infrastructure - wireless sensor network for condition assessment and monitoring of old pipelines.	▪ MIT Boston, USA (and University of Cambridge, UK)
Other countries	
Germany	
▪ Transponder technology to support the end-of-life phase in product life cycle management.	▪ University of Bremen (part of EU-project, PROMISE)
Norway	
▪ Smart embedded systems technologies for product lifecycle models.	▪ SINTEF, Trondheim (part of EU-project, PROMISE)
▪ Use of RFID technology in support of construction logistics.	▪ Agder University College, Grimstad
Canada	
▪ Integrating bar coding and RFID to automate data collection from construction sites.	▪ Concordia University, Montreal
Taiwan	
▪ Mobile construction RFID-based supply chain management systems.	▪ Chin Yun University, Taiwan
Japan	
▪ On-site inspection support systems using RFID.	▪ Muroran Institute of Technology, Fujita Corporation

Detailed descriptions of research areas:

Research Area: Supply Chain Management and Logistics - efficiency

Mobile Construction RFID-Based Supply Chain Management Portal System - Taiwan

Abstract: The construction project control aims effectively to obtain real-time information and enhance dynamic control by utilizing information sharing connecting from involved participants of the projects to reduce construction conflicts and project delay. However, extending the construction project control system to job sites is not considered efficient since using notebooks in a harsh environment like a construction site is not particularly a conventional practice. Meanwhile, paper-based documents of site processes are ineffective and cannot get the quick respond to the office and project control centre. Integrating promising information technologies such as radio frequency identification (RFID) technology and web portal can be extremely useful for improving the effectiveness and convenience of information flow in construction supply chain control systems. Radio frequency identification is appropriate for several construction
applications, providing cost savings through increased speed and accuracy of data entry. This paper demonstrates the effectiveness of a RFID-based supply chain management application in construction projects, called the Mobile Construction RFID-based Supply Chain Management (M-ConRFIDSCM) System, that responds efficiently and enhances the information flow between offices and sites in a construction supply chain environment. The advantage of the MConRFIDSCM system lies not only in improving the efficiency of work for on-site engineers, but also provide the kanban-like visual control system for project participants to control the whole project. Moreover, this paper presents generic system architecture and its implementation.

Institute of Civil Engineering and Disaster Reduction Technology, Ching Yun University, Taiwan - 27-10-2005

Opportunities in Improving Productivity by Developing Logistics Management and Systems - Finland

Abstract: This preliminary research and fact finding review will study what could be potential development areas in present logistics management and systems within the construction industry. The aim is to make an assessment about the present situation and provide knowledge about potential development areas. This project will also try to analyze benefits of the logistics development projects. The objective is that logistic processes will be based on and supported by 3D/4D product model. This would develop complete new thinking and processes that could utilize latest ICT, for instance RFID technologies that could enable faster development in productivity.

Confederation of Finnish Construction Industries RT, and co-sponsored by tekes - 2003 - 2007

Possible Use of RFID Technology in Support of Construction Logistics - Norway

Abstract: One of the areas that RFID technology may show great potential is the area construction logistics. Today, a construction site is a chaotic place, with materials stored at various locations and often little to none control as the materials arrive. The result of this is that delivery failures may not be discovered until the materials are to be used, which often creates unnecessary delays. If the materials were to be marked with RFID tags, these delivery failures may be discovered as the materials arrive at the construction site.

A prototype was also developed that was able to read the tags already present in the doors from Swedoor AB. The prototype is able to read the tags and send them to a server over the GSM network, where it can then be processed and the materials checked in. This prototype unveiled a serious problem with handheld scanners; the scanning distance is too short to use on a construction site due to limitations of the battery.

We conclude the report with the realization that RFID technology, as it is today, is too immature to deploy in the construction industry today.

Master Thesis in Information and Communication Technology, Agder University College, Grimstad, 2004-06-01,

Integrating Bar Coding and RFID to automate Data Collection from Construction Sites - Canada

Abstract: Tracking and control construction projects depends primarily on the nature, accuracy, frequency and time required to collect onsite data of construction operations. Automated data collection methods can improve data collection speed and accuracy in a cost effective manner. The bar coding technology, for example, was introduced in 1973 (Shepard 2005) to automate the process of data collection. At that time it was compared with manual data collection. Subsequently other technologies emerged to enhance the speed of automated data acquisition and circumvent some of the limitations of bar coding such as, 1) bar code reader must be very close to the label to be able to read information which consumes time and man-hour, 2) limited amount of information stored in bar code tags, 3) information can not be changed once it's stored, and, most importantly, 4) bar code tags can easily be damaged or lost. RFID works in a manner similar to that of bar coding (Jaselskis 2003), whereas in RFID data can be stored in tags and retrieved with readers that can communicate with the tags using radio frequency waves instead of light waves as in bar coding. Implementing RFID into the construction industry is tied with the cost associated with that technology. The ideal approach is to replace bar coding with RFID. This paper presents a data collection methodology that utilizes both RFID and bar coding technology to update project cost and schedule information. RFID components are described and its applications into different industries are highlighted. A comparison is also given between RFID and bar coding to highlight the advantages and limitations of each. This paper also identifies construction data needed for tracking and control process and examine the best technology to be used to collect this data. The type of data used is from the highway construction industry. This includes construction equipment used for excavation and paving activities, labour and material. Criteria like the cost associated the each technology such as the price of transponders and scanners and the use of active and passive RFID tags are taken into account. The proposed methodology is part of an undergoing research that integrates different data acquisition technologies to automate the process of data collection from construction sites, compare it to planned ones, and subsequently generate progress reports.

Building and Environmental Engineering, Concordia University, Montreal – November 2005

Improving construction-related manufactured products' supply chain by electronic tagging and tracking using wireless and web technologies - UK
Abstract: Demonstration project; This project aims to adapt and transfer technologies for electronic tagging, wireless communications and web technologies from the haulage, automotive and retail industries to engineering firms producing components and products for the construction industry. The objective is to develop and pilot a system for electronically tagging and tracking construction related products during manufacturing and installation. The main outputs are: 1) the development of generic software for tracking goods from order, manufacturer, delivery and installation 2) four live demonstration projects to show the technologies in use and project summaries showing the innovation 3) the business benefits of using these technologies.
Building Research Establishment (BRE) – 2002 - 04

Research Area: Product ID - using the right component and device

RFID & TETRA[73] in Pumps and Pump Systems- UK
Abstract; This project aims to transfer and exploit the radical data carrier and item-attendant data management benefits offered by RFID technology to pump-manufacturers and pump-users. Awareness seminars will be held for BPMA members to disseminate the potential offered by this technology. Selected BPMA members will subsequently develop a number of pilot-scale demonstrator programmes in conjunction with RFID systems integrators and technology providers. The technology is applicable both to manufacturers, where the item attendant data capacity can improve the efficiency and trace ability of manufacturing processes, and to the end users where the RFID tags will provide the capability for enhanced asset management and maintenance, with the potential for remote monitoring and diagnostics, intelligent distributed control and energy minimal control strategies through integration with TETRA. The BPMA has recognised the significance of AIDC in general and RFID in particular. Applications of RFID in manufacture, particularly in the automotive sector, have pointed to both parallel and innovative applications potential in the pump manufacturing industry and user community. Key areas of application include manufacturing per se, field services/maintenance, predictive monitoring, and energy management systems, pump supply and service strategies. In seeking to establish the potential for RFID, the BPMA has identified the need for a forum to assess the attributes and applications base for RFID and associated technologies and formulate both action plans and support materials to assist industry members in the beneficial adoption of RFID data carrier technology.
British Pump Manufacturers Association (BPMA) – 2001 - 04

[73] Terrestrial Trunked Radio (TETRA) is an open digital standard defined by the European Telecommunications Standard Institute (ETSI).

Research Area: Tracking and tracing of components, vehicles, parcels etc.

Field Trials of GPS Technology for Locating Material in Laydown Yards - USA

Abstract; This study assesses the potential for GPS technology to improve the tracking and locating of unique materials, in construction laydown storage. In the trial, a GPS unit and a handheld computer were integrated into current typical material receiving and issuing processes. Those processes were broken down into a series of distinct steps and the researchers measured the time required by field workers to execute those steps. Time measurements were taken for a baseline case in which crews used current typical industry work processes to locate spools. The researchers then measured times for separate crews locating the same pipe spools using GPS technology. The field measurements clearly quantified the time saved using the GPS system. The average time spent locating a spool using the current process was 6 minutes and 42 seconds, which was reduced to 55 seconds working with GPS system. The reduction of 5 minutes and 47 seconds per spool was validated by a statistical analysis. The researchers estimated that the GPS technology would have paid for itself in warehouse labour savings alone on a single project handling several thousand tagged items. In addition to these direct warehouse labour savings, the GPS system may also reduce the number of times material is handled and reduce the number of lost items.

FIATECH Consortium, USA - November 2004

Materials and Asset Tracking Using RFID: A Preparatory Field Pilot Study - USA

Abstract; The principal objectives of this pilot study were twofold: to assess the ability of RFID technology to significantly improve the efficiency, accuracy, and accountability associated with the movement of critical materials and supplies; and gain knowledge about the practical use of RFID technology and its implementation in a real life industrial application. Conducted in collaboration with the ChevronTexaco Energy Technology Company, the FIATECH Smart Chips Project, Phase IV Engineering, and the Tulane Consortium for Supply Chain Management, the pilot study analyzed thirteen shipments with a total of 154 specific items, tracked during transport between the shore based terminal and the offshore platform. Specifically, the report finds that the RFID technology was relatively easy to implement and functioned well, even in harsh marine weather conditions. When used in accordance with the relatively straightforward pilot project procedures, the RFID system accurately identified 100% of tagged items in each shipment in which the system was used. Marine weather conditions did not affect performance of the system. In some instances, the highly metallic environment on the offshore platform caused problems reading all RFID signals; this was resolved by changing the position of the reader with respect to the RFID tags. Other less significant technical issues encountered in the pilot could be easily resolved by minor adaptation of the RFID systems or procedures.

FIATECH Consortium, USA – September 2004

Field Trials of RFID Technology for Tracking Fabricated Pipe – Phase I - USA

Abstract; The field trials described in this report tested technical feasibility of active RFID technology in automating field materials management processes. A recent Construction Industry Institute survey identified Field Materials Management as the area that CII member company management thought had both: 1) the greatest potential for improvement and 2) the greatest positive development impact on engineering construction work processes. The trials described in this report were conducted in two phases. The first phase used handheld readers in determining the ability to read RFID signals at long distances and around metal. Handheld systems might be used for more efficient and accurate manual receiving and inventory applications. The second phase used a fixed reader and portal system that would be more typical of a fully automated commercial transport and receiving application. The results of the trials indicate that current active RFID technology can work very effectively in the construction field environment. The technology has the potential to both improve efficiency and accuracy of current manual receiving and inventory management processes, and eventually may enable full automation of these processes. A third phase of the trial is planned, in which the technology will be used in an actual project environment and potential benefits will be assessed.

FIATECH Consortium, USA - February 2004

Field Trials of RFID Technology for Tracking Fabricated Pipe – Phase II - USA

Abstract; The field trials described in this report tested the reliability of RFID technology in an application that would automate the critical task of documenting the delivery and receipt of uniquely tagged construction materials and equipment. Specifically, the trials tested the ability of RFID systems to accurately identify unique spools of fabricated pipe passing through a portal gate. This portal application was deemed to be one of the most technically challenging uses of RFID in a realistic construction environment because of the dense metal environment, the large number of items to be read quickly and the need for long reading distances. The results of the trials indicate that current active RFID technology can work reliably in such an application. In addition, the researchers interviewed industry practitioners and technologists in order to identify and describe some potential benefits of automating the tracking of unique materials at various points in the construction supply chain. The report describes typical generic steps in a construction supply chain, including fabrication, interim handling (e.g. third party painting of fabricated pipe), construction site receiving, issue to crafts, and installation progress. At each of these steps, we have identified some perceived inefficiencies and problems that might be addressed by RFID technology. The researchers concluded that RFID technology has the potential to both improve the efficiency and the accuracy of current manual tracking processes, and eventually could enable a more complete automation of these processes.

FIATECH Consortium, USA - August 2004

Electronic Tagging of Construction Products and Tracking with WAP and Web Technologies - UK

Abstract; Project that has been part funded under the UK's Department of Trade and Industry (DTI) ICT-Carrier programme. It aims to adapt and transfer technologies for Radio Frequency Identification (RFID), Wireless communications and Web applications from retail and haulage industries to the manufacturing sector supplying to the construction industry. The main objective of the project is to develop and pilot a system for electronically tagging and tracking construction related products throughout the supply chain. The solution is to use electronic RFID tags as a means of storing information with the product itself and updating the information throughout its journey, from manufacturer to construction site. This will help identify and locate products and update information during the entire process, including the intervening stages, such as: storage at the manufacturer or stockist site; correct loading of products for the correct destinations; tracking during transportation; delivery to the correct site and automatic registering of receipt of goods through a site scanner. It is also possible that it could be used as proof of delivery and as a paperless delivery note, which could then be used to automatically trigger invoicing and payment.

Building Research Establishment (BRE) – 2002 - 04

Research Area: Maintenance of service systems - Quality control

Smart Infrastructure - UK

Abstract: The original project sought to develop and evaluate prototype Wireless Sensor Network (WSN) systems for condition assessment and monitoring of old pipeline and tunnel networks.

The Smart Infrastructure KIC has expanded its core research into two new areas: MEMS - which offers functionality alongside miniaturisation and low power consumption, and optical fibre sensor technologies - which offer a full strain profile over long distances (eg of tunnels and pipelines).

The challenge of monitoring and maintaining a country's infrastructure is a significant one, but this project is trying to find new ways to meet it. The research — led by Prof Robert Mair at Cambridge University and Prof Andrew Whittle at MIT — aims to develop and evaluate new prototype Wireless Sensor Network systems for assessing and monitoring the condition of old pipeline and tunnel networks. Providing new solutions for monitoring ageing infrastructure is highly necessary. Many London Underground tunnels are over 75 years old, for example, and there are still miles of cast-iron Victorian water mains in the UK. The country also has 189,000 miles of public sewer network — which, according to a National Audit Office report in January 2004, demands new strategies to make sure it is properly maintained. But assessing the structural strength and useful life of assets like sewers, tunnels and water pipes is complex to do when they are buried. This is where the work of the project comes in. The research combines expertise within MIT in the mechanics of construction materials, applied information technology and non-destructive evaluation methods, with a strong geotechnical group at the University of Cambridge. This group has extensive experience in laboratory and field measurements of performance for civil infrastructure.

Already, the research team has developed brand new, wireless sensor technology and run a successful trial with industrial partners, London Underground Ltd. The trial ran during autumn 2003, after the research team was invited to develop and deploy a prototype wireless sensor network system to monitor the condition of a stretch of London Underground tunnel. London Underground had already installed its own tried and tested wired monitoring system in the tunnel to assess predicted settlement levels during the construction of the Channel Tunnel Rail Link nearby. The research team was invited to trial their wireless system alongside it, and to see how it fared in comparison.

The measured deformation data were sent by a wireless link inside the tunnel and transferred to a MIT server by a digital mobile phone line in order to show the data in real time. The group recently began investigating the use of fibre optics technologies to monitor the deformation of ageing infrastructure.

University of Cambridge, UK and MIT Boston, US - 2004 - 2007

An On-Site Inspection Support System Using RFID Tags and Personal Digital Assistants - Japan

Abstract; Inspectors of buildings including power plants have to carry a bulk of documents and drawings to perform their tasks otherwise they have to memorize extensive knowledge and data about the structures and facilities. Thus, a light and handy IT solution system for supporting inspectors is desired. In this research, we propose and develop a prototype on-site inspection support system. This system consists of a RFID tag system, a PDA connected to the Internet, a voice input/output system, and a digital camera. In our approach, senior inspectors' knowledge such as advices and warnings regarding each facility and structural member for inspection is input to RFID tags via voice at the site as if the inspector is teaching a junior inspector. And each RFID tag is glued to the facility or member. A junior inspector can obtain such valuable knowledge later on when he or she inspects the building alone from the reader-writer and PDA system. This system will enable senior inspectors to transfer their expertise that can be excited only at the site to a knowledge system. The information in the RFID tags can be altered or augmented when necessary. RFID tags can carry not only inspectors' advices and warnings but also the ID, main feature and recent inspection data of each facility or member. The inspector can have access to the corresponding drawings, specifications, data of testing, etc. from the ID of the RFID tag by the PDA. When more information is needed, the inspector can get information by the PDA from the headquarters databases via the Internet. The sound input system can be used to record sounds of various machines such as generators, compressors, sirens, etc. and the recorded sounds can be analysed and evaluated on site by this system. Digital photographs can also be taken and stored in the database and compared with the previous ones for inspection purposes.

Muroran Institute of Technology, Electric Power Development Co., Ltd., Fujita Corporation, Japan - June 2002

Using tagging and Wireless Technologies for Asset Maintenance - UK

Abstract; This project will support the agenda for implementing change & continuous improvements set up by Rethinking Construction and the Strategy for More Sustainable Construction and help reduce waste, transparency within the supply chain and use of innovative technology. 1) Examine technical issues/business benefits of using tagging &wireless technology in the maintenance of buildings 2) This project will build on previous work by Bovis Lendlease (on iTAG) and a DTI tagging project led by BRE, by using these technologies for maintaining/planning replacement of biolers in homes and fire doors/escalators 3)Demonstrate how these technologies can be integrated into existing maintenance and asset management systems by trailing their use in maintaining biolers in homes, and in tracking and maintaining fire doors/escalators.

Building Research Establishment (BRE) – 2004 - 05

Lessons learned from using sensing technologies for active project quality control - USA

Abstract: Defects experienced during construction are costly and preventable. Advances in sensor and tagging systems provide a way to capture the as-built history of a construction project to be utilized for quality control. Recent developments in generating 3D environments using laser scanning technologies (e.g. LADARs), and in acquiring quality information about built environments using embedded and other advanced sensors create an opportunity to explore the feasibility of frequently gathering complete and accurate three-dimensional and quality-related as-built data frequently throughout the construction and facilities management phases of a facility. Similarly, advances in Radio Frequency Identification (RFID) technology minimize earlier technological problems, such as metal interference, and economical limitations and can provide an environment to capture, store and communicate data related to the history of a component to be used for quality control during and post construction. This paper discusses on-going research projects at Carnegie Mellon, focusing on utilizing LADARs, embedded sensing and RFID technologies to capture the as-built conditions of a facility and assessing the capabilities of Industry Foundation Classes (IFC) for enabling the data capture and transfer in support of active quality control. These research projects included detailed case studies and field and pilot tests, during which we attempted to utilize these technologies, and standards for enabling active quality control on construction sites. The following sections will describe the lessons learned during these case studies from the perspectives of using these sensing technologies throughout the lifecycles of construction projects and the management and the analysis of the data captured from these technologies.

Civil and Environmental Engineering, Carnegie Mellon University - October, 2004

Research Area: Inventory Management

The Use of Smart Chip Technology in the Electrical Contracting Industry - USA

Abstract: Identification, tracking, and locating construction materials and tools are time consuming and man-hour intensive activities. Traditionally, a manual approach has been used to inventory and locate electrical materials and tools. This process consumes time and is prone to errors. Furthermore, traditional techniques of tool tracking have done little to reduce tool theft. According to the National Insurance Crime Bureau, approximately $1 billion worth of construction equipment and tools are loss to theft each year in the U.S. construction industry. Tool losses erode jobsite productivity and company profits, which are eventually passed on to the consumer of capital facilities in the form of higher prices. In order to help reduce the costs of tool losses, this research was commissioned by Electrical'21 to investigate how the use of smart chip technology to more effectively manage jobsite equipment and materials. In an effort to improve the efficiency of tracking tool and improve their availability, the research developed a successful tool tracking inventory system which is also capable of storing operation and maintenance (O&M) data using commercially available active Radio Frequency Identification (RFID) tags. With participation of electrical construction firms, the system was tested on a number of construction jobsites. The project demonstrated that active RFID can be used to inventory small tools and store pertinent O&M data on the tools in construction environments despite metal and other jobsite interferences. The research identified the need to standardize active RFID in order to greatly facilitate the incorporation of RFID tags by the tool manufacturers and promote the widespread use the technology.

Civil Engineering, University of Kentucky - July 15, 2004

Tool Management in Construction: An Initial Comparison of Accuracy and Scan Times for RFID and Bar Code Systems - USA

Abstract: An experiment was carried out in March of 2005 at the tool management facility of Zachry Construction in San Antonio, Texas. There were three research objectives: 1. Compare the average elapsed time it takes to scan a set of subject tools using two types of tool-identification systems: Radio Frequency Tags (RF Tags) and Bar Code Labels; 2. Measure the number of subject tools correctly identified; and 3. Determine if the location of the tools within a gang box has any effect on the ability of the RF Tag reader to successfully scan a tool. The main results of the study revealed a 3 to 1 advantage in tool-scanning speed for the RF Tag tool-management system. It took an average of 1.67 seconds per tool to correctly scan tools using RFID equipment. It took an average of 4.92 seconds per tool for the bar-code system. The RFID system was at a slight disadvantage to the bar-code system in accuracy although the researchers were not confident this would hold up in practice. The bar-code system was 100 percent accurate in these tests, and the RFID system was 98 percent accurate. There was no significant effect due to the location of a tool within the gang box.

Texas A&M University, College Station, Texas – 2005/2006

Research Area: Track recording of components and materials handling

Field Study of Concrete Maturity Method in Very Cold Weather - USA

Abstract; The study described in this report was to assess the reliability and potential benefit of using the concrete maturity method in very cold weather, which presents particular challenges for concrete construction, including: 1) assuring that fresh concrete is not damaged by the cold, 2) that the concrete reaches appropriate strength even where the curing process is slowed by colder temperatures, and 3) managing the additional and costly processes of heating and protecting concrete during curing. This report reviews the concrete maturity method, describes the technology, and describes field observations, and discusses potential benefits of using concrete maturity method and technology in very cold climates.

FIATECH Consortium, USA - August 2005

Field Tests of RFID Technology for Construction Tool Management - USA

Abstract; This report presents the results of field tests conducted by the FIATECH Smart Chips Project in collaboration with Zachry Construction Corporation, Texas A&M University, and HOUNDware Corporation. The purpose of these tests was to investigate the technical feasibility of using RFID technology to automate tool management processes. RFID technology offers the possibility that tools and valuable supplies tagged with RFID devices could be issued and received from central storage and the issue/receipt documented without intervention or help from a tool storage attendant. In addition, RFID tagged tools kept in distributed field storage boxes could be automatically inventoried in real-time on demand. Such automated systems have the potential to: 1) reduce theft, 2) optimize tool inventories, 3) insure that crafts have access to the appropriate tools as needed, and 4) reduce overhead labour cost of managing tools. The prototype RFID system worked reliably in all of the tests. The result of the Gangbox Test indicated that RFID technology is reliable in inventorying tools in field storage. The result of the Portal Test indicated that the RFID portal is capable of automating tool issue and receipt. It appears that those technical issues encountered during the tests (e.g. occasional missed tags) could be resolved with relatively little additional system development.

FIATECH Consortium, USA -June 2005

The Use of the Concrete Maturity Method in the Construction of Industrial Facilities: A Case Study - USA

Abstract; This report describes a FIATECH Smart Chips Project Field Trial of recent technology that accurately predicts in-situ strength of concrete using the concrete maturity method. The trial was conducted in realistic field conditions by Fluor Corp. personnel over two months during the main concrete placement phases of the Amgen Opus Program Project in Puerto Rico. The report describes the concrete maturity method, the technology used in the trial, and field experience with that technology.

FIATECH Consortium, USA - January 2004

Scoping Study to Evaluate the use of Wireless Sensors and Data Acquisition Systems for Cement, Smart Concrete and Concrete Products - UK

Abstract; This project looked at the feasibility of developing a wireless general-purpose data acquisition system (WLDAS) and a number of wireless sensors for use in for all industrial sectors. This provides a cheap, robust, easy-to-use, noise free and flexible solution for data acquisition in the environment. However, the project investigated the potential use of these technologies to facilitate process improvements in the manufacture of cement, concrete and concrete products, as well as monitoring key characteristics of concrete products in use. The final output of the project has been to produce a strategic document identifying the application of these technologies in construction, waste, oil and process industries and way forward on areas identified by organised workshops and questionnaire as being important to cement, precast concrete and concrete sector will be produced to map a way forward. This includes a summary of the issues, challenges and trends facing the industry over the next 3-5 years.

Building Research Establishment (BRE) – 2003 - 04

Embedded technology in Construction[74] (potential savings in construction for public building) - Denmark

Abstract: The report is a study based on the vision for Danish Construction Industry called "Vision 2020 - Intentions in Construction". The focus is on intelligent construction processes and buildings through embedded technology (RFID, sensors etc.). The background is two important challenges in Vision 2020: (1) Construction Industry and research institutions should make strategic co-operations for development of IKT solutions and implementation programmes for the industry. (2) Building contractors and property developers should set up demands for embedded IKT in construction material and building elements. Intelligent building elements will lead to more efficiency in the construction process and lower costs both in the long and the short run.

Danish Building Research Institute (SBI) - 2006

Automated Part Tracking on the Construction Job Site - USA

Abstract; Efforts are underway at the National Institute of Standards and Technology (NIST) to develop a webbased system for rapid tracking, identifying, and locating manufactured components on the construction jobsite. The approach involves the use of RFID and barcode identification systems, 3D long range coordinate measurement technologies, portable/wearable computers, wireless communications, high speed networking, temporal project databases, web-based data analysis, and 3D user interfaces to provide as-is and as-built component data at the actual construction site. These same techniques may prove useful for planning and execution of construction operations on other planets. Present research is focused on developing compact, rugged, wireless part status managers, interoperability protocols for data transmission, and 3D site visualizers which reflect the current state of tracked components on the construction site. Ultimately, these field measurements will be used to generate automated material acceptance and payment transactions, damaged component rejection notices, and production rate change requests to fabricators. This paper discusses the methods employed to achieve this capability in a prototype system.

National Institute of Standards and Technology (NIST), USA - November 2000

[74] www.sbi.dk - report in Danish

Research Area: Deconstruction of equipment - lifecycle

Utilization of RFID Tags for Accessing a Construction Material's History for Environmental Assessment - USA

Abstract: As LEED, Leadership in Energy and Environmental Design Green Building Rating System, certification is gaining acceptance in the building industry, designers, contractors and facility managers are finding themselves looking for information about production history of building components and about how to decommission them. As any environmentally conscious consumer, the buyers and users of various construction materials need to know what raw materials the product contains, how much energy was involved in its production, what toxic materials were used in the production process, and what should be done with the product at the end of its useful life. Current paper-based approach for transferring the environmental related information is ineffective since the supply-chain of each construction material is unique and requires transfer of the required information items among many different parties. With this paper-based approach, by the time a material arrives to a construction site or a facility is delivered to an owner, most of the environmental related information items get lost. If the information needed is stored in a digital form and gets transferred with the component itself, then information losses can be minimized. RFID, Radio Frequency Identification Technology, provides a way to store some information on the component and to access the environmental information needed by many parties along the supply-chain of a material. In the proposed research, the investigator will identify what information items need to stored on these tags, investigate what types of tags should be utilized for this purpose and experiment with a set of tags to assess their capabilities.

Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, - 2004

ETEK - RFID in Recycling Data Management of Electric and Electronic Equipment - Finland

Abstract: The project was partly sponsored by Tekes, the National Technology Agency of Finland. The project studied the applicability of RFID technology in the recycling industry. The requirements imposed by the WEEE and RoHS Directives served as the starting point. According to them, equipment must be marked with the producer's name and the date of introduction to the market in order to identify the producer. Furthermore, the producer must ensure that the parties involved in the life cycle of the product, users and authorised preprocessors, receive the required information associated with the reuse and recycling of the equipment.

It is probable that producers will mark their products with RFID tags. An RFID tag in the product can be used, among other things, for storing the product information specified in the WEEE Directive, which will allow more automated and efficient management of the information associated with product recycling. For example, waste could be identified and weighed on the disassembly line and, on the basis of the identification data, automatically and/or manually sorted to different waste treatment processes.

The recycling process is a challenging environment with regard to the application of RFID technology, due to high metal content. RFID equipment operating on frequencies of 13.56 MHz and 869 MHz was used in the studies. The subject of the study was the identification of display units and metallic collection containers. The identification of display units was studied in an industrial environment at the Kuusakoski Oy disassembly line, and the identification of collection containers at Ekokem Oy.

The product results indicate that RFID technology will have economically and technically justifiable applications in the processing chain of WEEE in the near future. The most important advantages of RFID technology identified in the project include product identification and association with the producer in any phase of the waste treatment process, precise distribution of costs among producers, the possibility for automatic sorting of products, availability of product information, improved efficiency of material flows, automation and improved efficiency of information management, and improved efficiency of collection container management.

VTT – Project period - 1 March 2003 and 28 February 2005 in Finland

PROMISE – Product Lifecycle Management and Information Tracking Using Smart Embedded Systems - EU, USA, Japan, Australia

Abstract: PROMISE is an endorsed IMS project (IMS project no. 01008) and brings together a large international partnership involving five IMS regions: EU, Switzerland, Japan, Australia and USA. The objective of PROMISE is to develop a new generation of Product Information Tracking and Flow Management system.

PROMISE will develop appropriate technology, including product lifecycle models, Product Embedded Information Devices with associated firmware and software components and tools for decision making based on data gathered through a product lifecycle. This is done to enable and exploit the seamless flow, tracing and updating of information about a product, after its delivery to the customer and up to its final destiny (deregistration, decommissioning) and back to the designer and producer.

The main elements of the PROMISE concept are:

- Product Embedded Information Devices (PEID) based on a combination of suitable existing technologies such as bar-code, RFID transponders and short as well as long range wireless communication technologies.
- Local (short distance) connection mode for product data and information exchange,
- Internet (long distance) product information and knowledge retrieval
- Data and information flows
- Envisaged decision support software

The breakthrough contribution of PROMISE, in the long term, is to allow information flow management to go beyond the customer, to close the product lifecycle information loops, and to enable the seamless e-Transformation of Product Lifecycle Information to Knowledge. The PROMISE R&D implementation plan includes fundamental and applied research activities in the disciplines of information systems modelling, smart embedded systems, short and long distance wireless communication technologies, data management and modelling, Design for X and adaptive production management for Beginning Of Life (BOL), statistical methods for preventive maintenance for Middle Of Life (MOL) and planning and management of product End Of Life (EOL).

EU FP6 IP Integrated Project (507100) recently accepted under the acronym PROMISE.

Using Transponder Technology to Support the End-of-Life Phase in Product Life Cycle Management (part of PROMISE) **– Germany**

Abstract: The first part of the paper describes opportunities of the RFID technology and its possible role in life cycle management. For improving the product life cycle management the features of the RFID technology will have a positive influence on closed recycling loops. By establishing a link between the customer and the producer or recycler of a product, new services can be implemented and existing ones optimised. The following paragraph will distinguish between 3 different mayor phases in the in life cycle of a product: Beginning of Life (BOL) - Product design (process) improvement: RFID technology appears as ideal solution to increase not only product data quantity but also quality and consistence available for the later usage in a (re-) design process. Smart products are in the position to log their individual history such as usage conditions, failure, and maintenance or service events. Product information based on the aggregated individual product MOL data is extremely valuable for the assessment or improvement of the product design process. Roles in this scenario are typically product designer or engineers, service or maintenance employees and the customer respective owner of the product. In opposite to the former processes of information gathering by market research and feedback collection from distributor or service agencies, this scenario provides more detailed information on product usage but also requires the active integration of the product owner to the overall processes.

Mid of Life (MOL) – Maintenance / Service processes: Process scenarios in this phase mainly covering the aspects of one single product, or an instance of a product. By attaching unique tags to a product, it is possible to establish

a linkage between the customer, the producer and the product, thus allowing for customer oriented updates, service, maintenance, etc. Such products, that are prepared to enable additional business via extra services, are also called smart products.
Smart products are able to provide information on how to use or how to maintain the product but they might be also providing information concerning the history its usage which is for example of particular interest for individual maintenance activities or complaints in case of product failures. Roles in this scenario are typically maintenance or service agency employees and product owners. End of Life (EOL) – Recycling and disposal: The availability of information about the product in this stage is on a low level, this means that waste manager have usually no opportunity to recycle the product or parts of the products on a better level than incineration or disposal. In addition to the information for the BOL and MOL phases, which is more directed on the user behaviour and general changes during the product using phase, the recycler needs information at a first level for rapid sorting processes (e. g. directed on brands and / or product types) and more detailed information for dismantling and component sorting processes e. g. by material, quality and functionality. At a glance the described scenarios can be considered as simple information management tasks not highly sophisticated from the technological perspective. More than this some of this information are still managed e. g. by Customer Relationship Management (CRM) systems and it seems that the integration of RFID technology simply shifts the emphasis of these scenarios from a more organisational to a more technical task.

Bremen Institute of Industrial Technology and Applied Work Science at the University of Bremen - 19. Mai 2004

Closing the Product Lifecycle Information Loops (part of PROMISE) **– Norway**

Abstract: This paper presents the new possible business practices and possibilities that are enabled by the product lifecycle management and information tracking using smart embedded systems (PROMISE) technologies, product lifecycle models, product embedded information devices (PEIDs) with associate firmware and software tools for decision making based on data gathered through a product's lifecycle. The aim is to enable and exploit the seamless flow, tracing and updating of information about a product after its delivery to the customer and up to its final destiny. The main focus of this paper is therefore to present the background of PROMISE and the new business possibilities arising from PROMISE, as this can give important input to how e.g. production systems, ERP-systems and value-chains must incorporate the expected changes in order to stay competitive.

SINTEF Technology and Society, Trondheim, Norway - 2004

Research Area: General or counting more areas

RFID Technology in Construction Industry - Finland
Abstract: In construction industry there are large additional costs due to missing or outdated information. New technologies allow wireless gathering of information from mobile devices, machines, persons and sensor systems to databases and distribution of this information to all stakeholders through Internet and mobile devices. RFID allows to link persons, machines, vehicles, devices and material, as part of the information and process management of different actors. The main objective of the project is to develop and apply RFID-technology and the related wireless and mobile information management in construction industry processes and in the maintenance of facilities. The benefit of the technology is assessed through carefully planned pilots. Based on the results of the pilots, a roadmap for RFID-technology implementation is prepared.
VTT, Finland – VAMOS programme - 2005 - 2010

RFID Tagging: Applications for the Construction Industry[75] - USA
Abstract: The purpose of this research project was to disseminate information regarding RFID to owner and contractor organizations, enabling them to take advantage of this emerging technology as it becomes commercially available. The project report also provides RFID manufacturers with relevant information regarding the needs of the construction industry so future RFID products better addresses the industry's needs. The scope of this research project includes (1) providing Construction Industry Institute (CII) member companies with a better understanding of RFID tagging technology (what it is, how it works, benefits, costs, and current applications); (2) understanding CII member company needs in terms of what applications will best suit their needs, the type of data that should be stored on each tag, and barriers to implementation; (3) pilot-testing applications in the construction and owner facility operations environment; and (4) assessing how RF tagging technology can be incorporated into a fully integrated, automated project process (FIAPP). This project also investigates ways to integrate RFID technology throughout the project life cycle, improving productivity, cost, schedule, quality, and safety. The primary areas are related to construction (personnel accountability, safety, rigging equipment, fleet management, measuring and testing equipment, quality, and material control) and owner operations. From the owner's perspective, asset management would provide the greatest benefit. At the point of manufacture, RFID tags could be encoded with specific information by the manufacturer that the contractor would use upon receipt for inventory control at the site, including preventive maintenance requirements that would apply throughout the component's life and during the storage cycle of the project. When the asset was turned over to the owner, the information stored on the RFID tag could be used to track the asset's life during its maintenance and operation period.
The Construction Industry Institute, based at The University of Texas at Austin - 12/01/2000 - 03/01/2001 - 08/01/2001 ; three publications and practical guides

[75] http://construction-institute.org/scriptcontent/more/rr151_11_more.cfm

Radio Frequency Identification (RFID) Technology and its Applications in the Commercial Construction Industry[76] - USA

Abstract: This paper is a report of Radio Frequency Identification (RFID) technology and its potential applications in the commercial construction industry. RFID technology offers wireless communication between RFID tags and readers with non line-of-sight readability. These fundamental properties eliminate manual data entry and introduce the potential for automated processes to increase project productivity, construction safety, and project cost efficiency. Construction contractors, owners, and material suppliers that believe technology can further develop methods and processes in construction should feel obligated to participate in RFID studies for the advancement of the construction industry as a whole. RFID can increase the service and performance of the construction industry with applications in materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, field operations, and construction safety. Contractors need to understand and take immediate advantage of the time savings low labour costs associated with new technologies, and lower rework costs that RFID systems ensure. This report analyzes the direct benefits of material management pilot studies conducted by Bechtel, Rohm & Hass and the National Institute for Standards and Technology (NIST). Furthermore, potential RFID applications, viii economic development, and challenges of implementing these RFID ideas in the commercial construction industry are also presented.

Future case studies and project RFID sampling are needed to increase contractor and owner awareness of the potential savings of human life, project-scheduling times, and project costs. RFID technology would enable work to be done at lower labour costs than presently being used. Today the construction industry as a whole must determine where RFID is applicable so that together they can overcome current limitations and provide improved RFID systems in the field of construction. Through further development and research, the testing of RFID in construction will make contractors and owners more familiar with their applications, opening the window of opportunity to a limitless potential of RFID applications in the construction field.

University of Kentucky, Civil Engineering Department, Master's of Science in Civil Engineering - Examination - April 24, 2003

Radio-Frequency Identification Applications in Construction Industry - USA

Abstract; This paper provides information on radio-frequency identification (RFID) and its potential applications in the construction industry. RFID involves the use of miniature read/write transponders that are capable of storing data in harsh environments. These transponders can be used in situations where optical scanning is not practical because vision is blocked or because labels fall off or become unreadable due to dust, dirt, or other contaminants. The technology is currently used in several applications outside the construction industry (e.g., reading meters, preventing theft of store merchandise, tracking railroad cars and intermodal freight containers, collecting tolls, and performing agricultural and animal research), and is seen as having potential in the construction industry. Potential construction applications for RFID technology discussed here include concrete processing and handling, cost coding for labour and equipment, and materials control. Conceptual design systems for these applications are also considered and developed. Discussions of limitations of RFID technology for construction applications include proximity of equipment, nearby metallic objects, costs, and workforce attitudes. Conclusions are drawn regarding possible future impacts on construction industry.

Iowa State University, June 1995

[76] Mike Schneider, University of Kentucky

Implementing Radio Frequency Identification in the Construction Process - USA

Abstract; This paper provides construction industry owners and contractors with information about enhancing their operations using radio frequency identification (RFID) technology. Radio frequency identification involves the use of tags, or transponders, that collect data and manage it in a portable, changeable database; communicate routing instructions and other control requirements to equipment; and can withstand harsh environments. A construction industry-RFID supplier workshop was held to disseminate information about this technology and to generate suitable application ideas for the industry. With the information gathered during the workshop, one application idea was selected and pilot tests conducted to learn more about RFID and its applicability to the material procurement process on a construction site. The pilot tests showed that RFID tags reduced the time required to download data into a company's material tracking system and could "flag" an item so an entry was not repeated. When scanning the tags, sun glare was not a problem as compared to using bar code labels. Although further analysis is necessary, RFID did show promise of being a beneficial technology as it relates to the materials receiving process. A flowchart is provided to assist contractors and owners in selecting the appropriate RFID system.

Iowa State University, - October 2002

More Profitable Business using RFID, wireless and related technologies - UK

Abstract; SMARTTAG will develop an industrial network for the oil, wastewater (including brewery), and corrosion and construction sectors to investigate the basic applications of RFID, wireless sensor and related technologies. The project will produce a state of the art review of these technologies and strategic documents for these sectors, identifying applications, learning from other sectors using these technologies and a vision for the way forward. RFID and sensors technologies are being increasingly and successfully used in manufacturing, primarily for operations management, and stock control and logistics. Basic RFID and tagging technologies are rapidly being miniaturised to improve quality and cost base. However application of RFID and wireless technologies is at their infancy in the process industries (such as waste water and oil), where there is a reluctance since such technologies are seen as incompatible with the flow-based instrumentation that is the primary mechanism for operations management. This reluctance is also found in the construction sector, which tends to deal with large, one-off projects, where there is a perception of high costs for these technologies and a lack of understanding of the benefits. The continued development and diminishing costs of these technologies is enabling sectors, such as retail and automobile, to make efficiency savings and provide them with a competitive edge to maintain or expand their market share. There is no fundamental reason why these technologies cannot improve the efficiency of manufacture and competitiveness in process sectors and SMARTTAG will encourage this through identifying best practices, identifying potential new products and processes that could be developed (such as tags incorporated in concrete to develop smart prefab panels) and broker the better uptake of innovation between sectors and the technology providers in order to generate improvements in the manufacturing process.

Building Research Establishment (BRE) – 2004

Smart tagging in Construction - USA

Abstract; In the future pervasive computing is expected to have a significant impact on personal and professional productivity. Smart Chips embedded in objects will provide a wealth of information including identification, instructions for installation, operation and maintenance, object monitoring and relational data from the in-situ environment. Some of the enabling technologies for the development of Smart Chips include *auto identification* (auto ID), *micro-electromechanical systems* (MEMS), the internet, wireless communication, localization systems, and other sensing technologies. Tomorrow's construction-oriented Smart Chips will merge these and other technologies to provide advanced logistic, installation, and operating capabilities throughout the construction project life cycle. The background summary presented below is by no means exhaustive given the scope and pace of development in these areas.

National Institute of Standards and Technology – 2003

Electronic Tagging Technologies in the Construction Industry - - UK

Abstract; Mobile technologies bring new potential to modern information society (D. Rebolj, 2004). Indeed through the authors industrial experience the use of mobile technology is rapidly increasing in the construction industry. The wider use of this technology within the industry gives us the ability/tools to incorporate other innovative technologies such as automatic identification technologies (Electronic Tagging/RFID systems). These require mobile or '*wireless'* technologies to make their use worthwhile on construction projects. Wireless and tagging technologies have been successfully used in several sectors of industry and shown significant benefits to their users. The potential for cost savings and productivity improvement through the uptake of these information and communication technologies for the industry is estimated to be in hundreds of millions of pounds (R. Bassi & F Parand, 2002). This research is an investigation into what 'Electronic Tagging Technology' is and identifies possible applications for it in the construction industry, highlighting the benefits and constraints.

School of Construction and Property Management, University of Salford, Salford, Greater Manchester – 2005

Architecture for Discrete Construction Component Tracking - USA

Abstract: Accurate and timely identification and tracking of construction components are critical to operating a well-managed and cost efficient construction project. Establishing standards to support identification and tracking technologies has the potential to enable the construction industry to seamlessly integrate work processes at the job-site. This paper discusses on-going research at the National Institute of Standards and Technology to develop means for real-time component identification and tracking in the application of field sensors, portable computers, real-time high-precision global positioning, wireless communications, and construction project databases.

National Institute of Standards and Technology – 2000

Appendix III: Summery Questionnaire

Comments from interviews and workshops

The interviewed persons and workshop participants represent different parts of construction industry, contractors, suppliers, consultants and advisors, researcher, retail (DIY), operators and building owners.

Company names: Arcona, Atkins, Beta technic, Byggeriets Innovation, Danogips, Danish Technical University, Dansk Byggeri, DT Group, GBC Bygglogistik, Lambertssons, Lund University, NCC, Optimera, PEAB, RAMIRENT, Safetool, Skanska, Siemens, Swedoor

Drivers for RFID in the sector?

- Computerisation
- The manufacturers of the technology. Businesses with handling logistics issues. No drivers from construction companies.
- Large multinational companies
- Mandate, Cost reduction
- Competition and cost efficiency. Customer service has a small or no importance. The technology will come to use for constructors and the supply chain.
- Demand for traceability of products. Technology that will contribute to the use of automatic ID instead manual registration.
- Reduced capital cost, better work- and safety environment, rationalise the constructions sector.
- The need for security control. Precise and exact delivery control. Theft, counterfeit and fraud. Ensure quality throughout the products life cycle with origin labelling.
- The limitations that comes with the barcode.
- 4D building information model
- improving of supply chain efficiency and cost savings
- use technology (RFID,…) to decrease manual and routine tasks: release experienced employees to focus more productive tasks modelling
- IT for procurement systems
- internal production management (factory, construction site)
- boom of maintenance services, life cycle view
- SCM with its several “sub-areas”: logistics, procurement,…
- development of product-ID
- product-ID as a tool to link ICT systems and applications: modelling,…
- Elimination of waste (errors)
- Just in time delivery
- Supply chain integration
- Real time information
- Traceability of components, vehicles etc
- Service/maintenance efficiency
- Supply Chain Integration
- Efficiency, theft loss, confirmation of presence/attendance, location & knowledge of assets

Who is driving development in the sector?

- Material producers/suppliers, nothing is going to happen before they are active
- Organisations, enthusiasts and companies with own purpose
- Suppliers of materials and logistics companies. Constructors to reduce theft and improve logistics.
- The customer. The demand derives from the customer and will affect the supply chain backwards.
- Svenska Byggindustrin, Safetool AB and the union (indirectly)
- BEAst. Construction and facility managements electronically business standard, and its associate companies.

- Swedoor
- large contractors *(several hits)*
- organisations to manage real estate property assets (maintenance)
- assembly subcontractors at building sites (windows, kitchen equipment etc.)
- owners/users of buildings
- smaller construction and manufacturing companies (pressure to develop internal production/logistics processes)
- manufacturing companies (pressure to develop own processes and ICT interfaces)
- Volume manufacturers of products to the industry
- Asset Managers
- I'm not sure that anybody is apart from product manufacturers and a few enthusiastic
- individuals in some leading clients contractors
- Innovation & operations

Priority of RFID compared to other development projects (ICT etc.) in your company/institution?

- Identification due to lack of control of unregistered workers
- No priority directly for the technology but if it is in line with other development projects it could be of interest. See the technology as a tool within a bigger picture.
- Once working flawless it will have the highest priority.
- Low priority, the priority for IT is to a great extent higher.
  NCC has just learned about the technology.
- Low priority. Optimera is currently working on many other projects.
  Impossible to start this project on our own, requires the help from our suppliers.
- Some priority concerning gate control. Low priority compared to the development of electronically based purchasing systems. Prioritise development of a standardised identification system in front of RFID.
  Continued investment in RFID. Prioritise lean management to raise quality,
  RFID is used as a tool in this model.
- Mobility, utilization of wireless networks
- SCM in top 3 priority
- RFID is one of the potential enablers in SCM
- Among of top priority, some investments have already been done due to coming RFID implementation
- Important part of whole ICT development
- RFID and ICT development has to be done together (RFID tag is "just" a code carrier, information systems are for data and information management)
- RFID is not currently being pursued in a development project.
- It is relatively low on the current agenda, but awareness is growing rapidly with potential opportunities being identified

Research in RFID in Construction - lack of knowledge or development trends?

- Research is a must. This sector suffers from a lack of ability to spread information throughout the chain and also sometimes within companies. It is very hard to distribute gained information and make changes.
- Research will create new areas of use. Don't think any research is necessary for the technology itself. Perhaps research will help to develop a common platform.
- Cost focus on industrialisation. Press costs for material and logistic. Continual environmental focus.
- The knowledge exists. We need development trends and methods for implementation.
- Product identification
- Development trends. There is a need to make the technique clear and understandable.
- Development trends prior to lack of knowledge. What it takes is to present RFID´s potential to rationalise for daily use. It has to be possible to compare costs in cases where RFID is used and not used. Relevant competence has to exist in all parts of the chain.
- Lack of knowledge dominates this sector. People must be enlightened.

- "Technology push" is not needed. The problem has to be solved first, after that suitable technology comes by itself.
- More applications are needed
- Lack of basics for ROI calculations
- Level of knowledge varies among companies
- Ideas and real insights how to utilize RFID are missing
- The technology is proven. It is the integration of systems and supply chains that will achieve benefit realisation. This 'void' is a commonly researched problem in the sector that remains unresolved.
- Need for more practitioner case studies and input – sharing of experience
- Not Known

General development trends in the construction sector?

- Computerisation
- Finally money has been put in developing industrialised building. Otherwise no development.
- Less suppliers and closer relations/collaboration between customer and suppliers.
- Industrialisation of the business
- The development today is high. In general it is to increase the efficiency and reduce costs.
- Make the supply chain digital. Today Skanska, NCC and PEAB all have their own systems. The system that PEAB uses works and an added value is experienced. Suppliers have begun the usage of a common ID system.
- Lessen the number of suppliers which will lead to more "complete" suppliers.
- 4D building information models.
- RFID will not be top priority
- Alliances/supply chains start to compete with each other, not only single players.
- Deeper co-operation, for example assembly functions at partner's premises.
- Building model vs. document based information management in planning, building etc: product-IDs will help to link physical and digital world together
- Building Information Modelling and asset management systems are growing approaches. Attaching additional attributes such as RFID data is a natural extension of such 'database' technologies
- Snagging, inspections, collaboration, ICT, handheld usage, energy/waste management,
- Improving quality

Short term development in construction - RFID and ICT?

- Gate control
- Ordering via internet.
- Develop applicable and easy to use systems. Security, identification systems for entering and leaving construction site, means to control the logistics flow. ID cards to prevent unregistered labour.
- Almost non existent
- Today pilot project and within 3 years public knowledge
- ICT is an important part to increase the efficiency and reduce costs.
- Development of an ID system. Today the system is used in approximately one third of PEAB´s projects. The project with gate control and tool labelling has happened locally within the concern and has not been lead from the top.
- Things are about to happen, the interest is just starting to take off.
- Focus is into tracking and tracing of project based items (mass customization): unique building components such as concrete elements, windows,…
- RFID will probably not break through
- SCM based solutions
- Improving interoperability, use of 3D modelling, collaborative working

Long term development in construction - RFID and ICT?

- Quality assurance
- If one could find a way to implement RFID in the supply chain where more than one possible field

of use would be covered the potential of spreading the technology is huge.
Believe in RFID if the tag can be used from warehousing to construction.

- Will become indispensable for the construction industry.
- Follow the structures status throughout its development and lifecycle with for example active sensors and RFID.
- The technology has a massive potential. It's important to clarify this potential and clearly demonstrate its benefits and what this will mean for the end customer.
- Will have a large impact on warehousing and physical inventory. The information transparency will improve and become more simplified.
- ICT yes! Will be implemented in 5 to ten years. Don't think RFID will be implemented in the supply chain in that perspective of time. Maybe RFID will be used in specific parts such as maintenance of service systems.
- Once the ground work's done with a fully developed ID system there is room to implement RFID.
- It would be wise to create conditions for RFID before RFID is put to use. Sensors and RFID. Ought to be able to have a common identification system in the entire supply chain. The obstacles of paperwork have first to be overcome. Today for example Denmark has a law that requires Swedoor to put an actual visible label on their doors. A requirement like this has to be able to be replaced by RFID.
- Focus is extended to cover more difficult items such as bulk construction materials
- Expansion of RFID implementations at whole sector
- Maintenance service based solutions
- Improving interoperability
- Integrating supply chains & life cycle management

Appendix IV: Glossary

Active Tag: A type of RFID tag that has its own power supply (battery or external power), and, when interrogated by a reader, emits its own signal. Typically, active tags have far greater read distances than passive tags, and they can be combined with sensors to provide information on the environment and condition of the item. They are also more expensive than passive tags and due to the battery have a limited life span.

Agile Reader: A generic term that refers to an RFID reader that can read tags operating at different frequencies and/or using different methods for communicating between the reader and the tags.

Antenna: Conductive elements designed to radiate and/or receive radio energy. As part of an RFID system, antennas radiate or receive radio energy to/from the RFID tags and the reader.

Anti-collision: A general term encompassing the means of preventing radio waves from one device from interfering with radio waves from another. Anti-collision algorithms enable readers to read more than one tag in the same reader's field.

Auto-ID Center: The private/academic consortium founded in 1999 in conjunction with the Massachusetts institute of Technology. Through the support and cooperation of major manufacturers, retailers, and the U.S. government, the Auto-ID Center conducted much of the foundational research on commercializing RFID technology and invented the concept of the Electronic Product Code. The Auto-ID Center consortium became EPCglobal in 2003.

Automatic Identification (auto-ID): A broad term encompassing technologies used to help machines identify objects. A host of technologies fall under the Automatic identification umbrella, including bar codes, biometrics, smart cards, voice recognition, and RFID.

Backscatter: A method of communication between passive RFID tags and readers. RFID tags using backscatter technology reflect back to the reader radio waves from the source, usually at the same carrier frequency. The reflected signal is modulated to transmit data.

Capacity: The number of bits or bytes that can be programmed into a tag. A tag's capacity may represent the bits accessible to the user or the total number, including those reserved to the manufacturer (e.g., for parity or control bits).

Electronic Article Surveillance (EAS): Acknowledged by many as the first RFID technology widely used in the retail environment and in libraries, these systems use microwave or inductive technology "readers" to detect the presence or absence of EAS tags as a means of detecting and deterring theft. When an item is purchased (or borrowed from a library), the tag is turned off. However, when someone passes a gate area holding an item with an EAS tag that hasn't been turned off, an alarm sounds. These tags are inexpensive and do not contain any data.

Electronic Product Code (EPC): A unique number, stored in the chip on an RFID tag, which identifies an item in the supply chain, allowing for tracking of that item.

Electrostatic Coupling: systems that transfer data or power by inducing electrical voltage on a plate.

EPCglobal: The non-profit organisation that manages standards and numbering schemes associated with the EPC (Electronic Product Code). it is the successor organisation to the Auto-ID Center. EPCglobal is a subsidiary of the Uniform Code Council and EAN International now changed name to GS1, the leading retail bar-code-standards organisations. EPCglobal's membership includes leading retailers, manufacturers, and governments from around the world.

European Article Numbering (EAN): The bar code standard used throughout Europe, Asia, and south America, and administered by EAN international. See also GTIN.

Factory Programming: The process of having an identification number written into the read-only microchip of an RFID tag at the time the chip is made.

Field Programming: Tags that use EEPRom

(Electrically Erasable Programmable Read-only memory), or non-volatile memory, which can be programmed after being shipped from the factory.

Frequency: The number of repetitions of a complete wave within one second. For example, 1Hz equals one complete waveform in one second; 1KHz equals 1,000 waves in a second. RFID tags use low, high, ultra-high, and microwave frequencies. All frequencies have their own advantages and disadvantages that make them more suitable for some applications than for others.

Frequency Hopping: The protocol used to prevent readers from interfering with one another in their operations by using varying frequencies. In the U.S., even though UHF RFID readers are said to operate at 915 mHz, they actually can operate between 902 and 928 mHz. To avoid conflict with readers operating adjacently, a reader must "frequency hop"—jumping randomly or in a programmed sequence to any frequency between 902 mHz and 928 mHz. If the available band is wide enough, the chances of two readers operating at exactly the same frequency is therefore small. However, as the UHF bands in Europe and Japan are much smaller than those available in the U.S., the frequency hopping technique is not nearly as effective for preventing reader interference.

GDSN: Global Data Synchronization Network - created by the European Article Numbering association, the Uniform Code Council (EAN, UCC - now called GS1) and industry leaders worldwide, the GDSN is a network of interoperable data pools that connect to Global Registry.

GS1: GS1 is a leading global organisation dedicated to the design and implementation of global standards and solutions to improve the efficiency and visibility of supply and demand chains globally and across sectors. This is a merger between the former EAN International and former Uniform Code Council (UCC). The GS1 system of standards is the most widely used supply chain standards system in the world.

GTIN: Global Trade Identification Number - the new term for EAN number and UPC number - barcode that used for product identification.

Harvesting: The method by which passive tags gather energy from an RFID reader's antenna to be able to respond to the reader.

Inductive Coupling: systems that transfer data or power by inducing electromagnetic current in a coil.

Interrogator: Another name for an RFID reader.

Memory: The amount of data that can be stored on the microchip in an RFID tag.

Nominal Range: The range at which systems can assure reliable operation, considering normal variability of the environment in which it is expected to be used.

Passive Tag: A type of RFID tag that does not have its own power supply. Instead, the tag draws power from the reader, which sends out electromagnetic waves that induce a current in the tag's antenna. Without an onboard power source, passive tags have a lesser read range than active tags. However, they cost less than active tags and have a theoretical unlimited life span.

Phantom Read (also called a "phantom transaction" or a "false read"): The result of an RFID reader inaccurately reporting the presence of an RFID tag that does not exist.

Power Level: The amount of radio frequency (RF) energy radiated from a reader or an active tag. Higher-power outputs enable longer read ranges. However, most governments regulate the power levels at which RFID readers can operate to avoid interference with other RF devices.

Programming a Tag (also called "commissioning a tag"): in the context of RFID, the process of adding identification data to or altering the data in an RFID tag.

Radio Frequency Identification: An automatic identification technology that uses radio waves to identify objects.

Read: The process of retrieving data stored on an RFID tag by sending electromagnetic waves to the tag and converting the radio waves the tag sends back into data.

Read Rate: The number of tags that can be read by an RFID reader in a given time period.

Read/Write: The ability of an RFID system to change the data that is stored in a tag. For exam-

ple, as a product moves from the final packaging area to the warehouse, a read/write tag can be modified to reflect the new location, so that now, when interrogated, it passes the new location as part of its updated data stream.

Reader (also called an interrogator): A device that communicates with RFID tags. The reader has one or more antennas, which emit radio waves and receive signals back from the tag. Readers may have a digital display to relay information to the operator and may transmit data on to an organization's computer network infrastructure. Readers can be either fixed or portable, and today they are beginning to be integrated into other electronic devices, such as PDAs (personal digital assistants) and cell phones, and even into objects such as pens.

Reader Field: The area of coverage for an RFID reader. if a tag is within the reader field, it can (should) receive the reader's radio wave and be read.

RFID: The acronym for Radio Frequency identification.

Semi-passive tag (also called battery-assisted tags):
A type of tag similar to an active tag in that there is an onboard battery. The battery is used to run the microchip's circuitry and to boost the effective read range of the tag. some semi-passive tags sleep until they are woken up by a signal from the reader, which conserves battery life, while some are programmed to broadcast at set intervals of time.

Sensor: A device that responds to a physical stimulus and produces an electronic signal reporting on that stimulus. Sensors can be tailored to report on a variety of environmental conditions, including temperature, humidity and vibration.

Signal Attenuation: The weakening of radio frequency (RF) energy from an RFID tag or reader.

Slap and Ship: The practice by a manufacturer of placing RFID tags on cases and/or pallets at the last possible point before shipping from a supplier to a mandating retailer or other organization. With a slap and ship strategy, a manufacturer or distributor is simply trying to meet the requirements of another firm's RFID mandate, rather than attempting to capture any data—and value—from RFID tagging in its own system.

Smart Label: A generic term referring to a printed label that typically contains printed information, a bar-code identifier, and an RFID tag. The label is considered to be "smart" because of its ability to communicate with an RFID reader.

Time Division Multiple Access (TDMA): A method used to solve the problem of signals from two readers overlapping and colliding. TDMA algorithms enable the readers to attempt to read tags at different times.

Transceiver: A device that can both transmit and receive radio waves.

Uniform Code Council (UCC): The non -profit organisation that oversees the Universal Product Code (UPC), the bar-code standard used in North America. See also GS1.

Universal Product Code (UPC): The bar-code standard used in North America and administered by the Uniform Code Council (UCC). See also GTIN.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