Client Report :

The use of RFID technology in the off site manufacturing sector of construction

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Prepared for :

Mr Colin Dowling
Basic Technology
DTI

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Prepared by

Signature	
Name	Dr R Bassi
Position	IT Consultant

Approved on behalf of BRE

Signature	
Name	K Esmail
Position	Director, E Business Solutions
Date	31 January 2004

BRE
Knowledge Division
Bucknalls Lane
Garston
Watford
WD25 9XX

Tel : 01923 664800
Fax : 01923 664790

Email : knowledge@bre.co.uk
Website : www.bre.co.uk

Executive Summary

This Basic Technology project, 'More Profitable Business using RFID, wireless and related technologies', was commissioned to identify where RFID could be applied within the waste, oil and off site construction and its likely impact. This report constitutes the second milestone 2a for the project which is for the off-site construction sector. RFID technologies and examples of their successful implementation in other sectors and the trials of introduction into construction manufacturers under an existing ICT Carrier Project clearly show potential for their use in off site manufacturing were reviewed in Milestone 1. This report gives brief background on the off site construction sector and discusses the possible impact of these technologies in the off site-construction.

The UK construction industry accounts for 10% GDP of the UK i.e. approximately £100 billion per year. One third of this is accounted for by manufacturing i.e. £30 billion, and construction manufacturing accounts for 20% of the UK manufacturing base. One tenth of construction manufacturing i.e. £3 billion is accounted for by off site manufacturing. The manufacturing of precast concrete elements is also classified as off site manufacturing and according to the British Precast Concrete Federation its annual turnover is £1.6 billion. The annual growth of this sector is in the order of 18-20% per year and many of leading experts in the field believe that within several years the off site construction sector will have a turnover of £30 billon per year i.e. 6% of the UK manufacturing base. The off site manufacturing sector is seen as a sunrise industry, which is essential if various government targets on housing, health and education are to be met.

On the basis of the evidence of savings and efficiency improvements in other industrial sectors and the limited trails undertaken in construction, it is envisaged that if ICT were applied to the manufacturing, logistics of manufactured products and installation, the cost savings to an off site manufacturer would be in the region of 1-3% resulting from improved inventory, manufacturing process, stock control, delivery of correct product and installation.

Hazlin of Ludlow, a door manufacturer involved in a DTI ICT Carrier RFID project "Tag and Track", has estimated if RFID application was applied throughout its manufacturing and logistic process it would save between 2-5% per year.

It is estimated that the adoption of the technology by UK off site manufacturers supplying to the construction industry within the next 5 years could lead to annual savings in the order of £10m to £30m. Another significant tangible and intangible benefit would be reduction in litigation costs which normally occur mainly due to lack of delivery records and mismatch of specifications with delivered goods.

The technology also offer the opportunity to produced high value bespoke components within the same time scale and cost of mass produced components. Hazlin of Ludlow

produces bespoke high value fire doors and have identified that it is feasible to use RFID technology to convert the production of these doors to exactly like mass produced doors i.e. no one door on the production line is the same. The RFID tags in the door are read by the appropriate machine or operative using a tag reader, which instructs them on the operation to be performed. In the case of machines the integration of RFID technology will automate the whole process. Hazlin has estimated that the automation of the cutting operation of the door by their route can save them over 600 minutes a week and reduces the reliance on the few machine operators for the router. Similar applications of RFID technology can be extended to the off site manufacturing sector and if this was to happen this would allow the sector to offer a much wider rage of products and lead to further growth in the sector.

The benefits for both the manufacturers and their clients extend far beyond the procurement and delivery stages. For example, the tags and information linked to databases will have major benefits downstream the supply chain and the maintenance, re-ordering of correct parts, health and safety in operation and safe disposal of products will also be significantly improved. The application of technology can also be extended to the design and manufacture of products and the upstream supply chain with similarly significant benefits.

The study has shown that the awareness within the target sector of the proposed technology is very low. For this reason it is recommended that the model currently being used in the existing ICT Carrier Project on encouraging the use of RFID in construction, using demonstration projects, be used to facilitate the use of these technologies in the off site manufacturing sector such that tangible and quantitative benefits of using RFID and wireless technology can be demonstrated.

Several leading companies and clients in the off site sector were interviewed under this scoping study and all the firms said they would adopt the new technology if its benefits could be demonstrated via a demonstration project.

It is recommended that demonstration projects showing the commercial benefits of using tagging and wireless technologies for improving the off site manufacturing supply chain for a range of construction products should be undertaken further. In order to make the demonstration projects effective and achieve the aims, there need to be a buy in from the industry such that serious issues regarding the technology are universally accepted and adopted by major players within the industry. This would be achieved if the projects involve the top contractors, which account for 25% of construction turnover and large building owners. Coupled with an effective benefits and technology awareness dissemination strategy will encourage rapid uptake of the technology.

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Introduction

This project aims to study the potential benefits, applicability and obstacles in the use of a RFID and relate technologies for off site manufactures in construction. The project is carried out under the Basic Technology Programme of the Department of Trade and Industry.

This report constitutes the milestone 2a report for the project and looks at the impact of ICT technology on the off site construction supply chain. These technologies were reviewed in detail, see Milestone 1 report. This report gives background information, discusses the impact of these technologies on the off site manufacturer sector and makes recommendations on transfer of technology to the target sector.

1 Background Information

It is probably true to say that there are more types of construction in the UK than in almost any other country in the world and the number of different types is growing. The construction industry is changing, as market forces are driving the industry to reconsider their approach to serving their customers. Government agendas on Rethinking Construction, planning policy and building regulations are forcing the industry to reconsider the way buildings are built. These issues together with a construction skills shortage and a huge demand for new houses and buildings means that innovative construction types are being developed and used.

What is 'off-site production?'

Off-site production of building systems refers to forms of construction undertaken in a factory, rather than on a building site. Buildings are manufactured as a kit of parts or complete product assembly. Numerous terms are used to describe this type of construction, by far the most common being prefabrication. Other terms also used to describe this process include: off-site assembly, modular construction, industrialised construction, pre-assembly and system build. The term 'off-site production' is used to cover all forms of construction where a significant part of the process takes place in a factory. This can range from wall sections delivered to site and assembled to form a building frame, to entire pre-finished room modules.

It would be misleading to think of off-site production as being synonymous with standardisation. Standardisation implies repetition of components, dimensions and form – while these attributes can make the manufacturing process more efficient and simpler, they are by no means a pre-requisite for innovation. Many traditionally built houses made extensive use of standardisation, whereas many modern innovative schemes have produced highly varied developments.

Changing the UK building industry from an approach based on craft skills and project management to one founded on automation and factory production techniques will inevitably meet with some resistance. There is still, understandably, much scepticism regarding off-site production by those who claim that there is little room to change the way

Current developments

There are a number of reasons for the current shift towards prefabrication. Some are political, while others are the result of circumstances that prevail in the building industry. The most obvious political driver at the moment is "Rethinking Construction", the report of the Construction Task Force (published in 1998, also known as the Egan Report) and the subsequent launch of the Movement for Innovation (M4I) and Housing Forum; both have now merged into a new organisation known as Construction Excellence (CE). In the social housing sector the Housing Corporation (HC) have strongly supported both the activities of the Task Force and the Housing Forum and have let it be known that within the coming two or three years they will expect any schemes that they fund will need to be 'Egan compliant'. They launched the 'Kick-start' initiative for which £80 million of their

Assisted Development Programme (ADP) funding over the 2001/2002 and 2002/2003 financial years was ring-fenced specifically for factory produced housing.

Many private sector builders are also looking seriously at prefabrication for building houses, schools, hospitals etc. One of the main drivers for their interest is the skill shortage, coupled with an ageing workforce. These two factors mean that it is becoming increasingly difficult for builders to get reliable, skilled workers for conventional sites. Younger people no longer regard the construction industry as being able to offer suitable career opportunities - this is in part because of a poor image, namely that of having a muddy field as a place of work. Another factor pertinent to builders is the latest round of reviews for different parts of the building regulations. In particular the requirements for both thermal and acoustic performance are becoming more onerous, not least because of the threat of performance testing of the finished buildings.

The Movement for Innovation (M4I) was launched in November 1998 to facilitate the cultural change within the construction industry identified as necessary in the Egan Report. M4I identified four priorities for innovation and change. These were product development; project implementation; partnering the supply chain and production of components. These are now known as the four 'Ps'. Five drivers for change were also identified which were customer focus; a quality driven agenda; committed leadership; integration of processes and teams around the product and commitment to people. In order to be able to measure the extent to which companies were achieving objectives set by the Task Force, a series of annual targets have been set out which are:

- A 10% reduction in capital costs
- A 10% reduction in construction time
- A 20% reduction in defects
- A 20% reduction in accidents
- A 20% increase in predictability
- A 10% increase in productivity
- A 10% increase in turnover and profits

In December 1998 the Housing Forum was launched to promote innovation in the housing sector via a number of mechanisms including the development of industry key performance indicators, seminars, demonstration projects and the Off-Site Manufacturing Working Group.

From the thermal performance viewpoint there is a penalty to be paid in terms of increased wall thickness as the required U-value decreases. Framed solutions, which lend themselves more readily to prefabrication, can in general offer the same U-value for a thinner construction. Good acoustic performance needs good quality workmanship if it is to be achieved. While both masonry and prefabricated constructions are able to meet the proposed standards, many builders feel that off-site manufacture offers a better prospect of achieving consistently high standards compared to site-based masonry construction. As regulations become more onerous and clients see the improvement in quality available from prefabrication it is likely that an increasing proportion of houses will be built this way.

Technical developments

There have been a number of significant technical developments that make today's manufactured housing different from that of the past. Materials have improved, standards have been tightened, and building physics is much better understood. These factors

mean that there is no reason why historic problems related to the corrosion of steel frames, cracking of concrete and condensation should be repeated. In parallel with these improvements new products have evolved to deal with particular problems and issues, and technology is being imported from other countries and other sectors of the industry.

Housing

The demand for new housing in the UK is significant. Government predictions suggest that between 1996 and 2021 the total number of households will increase by 3.8 million, an average of 152,000 per year. The bulk of these (more than 70%) is predicted to be one-person households. This fact, coupled with recent policy shifts towards building at higher densities, means that the majority of the new dwellings to be constructed will be in the form of high-density terraced and purpose built flats. Within the social housing sector it is estimated that from 2002 to 2016 just under one million new dwellings will be required.

This presents a significant challenge to the UK construction supply chain with its diminishing labour force and increased business performance demands. Furthermore, client requirements for higher building standards and the industry's increasing regulatory improvements, particularly in thermal and acoustic performance, and health and safety issues are pushing the industry to reconsider on-site methods of construction and to investigate other ways of constructing buildings. To support these policy changes, government-backed reports such as 'Constructing the Team' (Ref 1) and 'Rethinking Construction' (Ref 2) have clearly identified that the construction industry must change its way of working if it is to prosper. Construction companies must address market demands of improved efficiency, better quality and performance, faster construction and better value and cost control.

Other pressures to change the way we build have come from increased concerns about the impact of the construction process on the environment and local communities. This has lead responsible and leading clients to take stock of the sustainability impacts of how we build, operate and maintain buildings. Off-site production techniques provide the construction industry with an approach to building that can address market demands, technical needs and process requirements.

Pro's and Con's of offsite production

As with any technology there are advantages and disadvantages. From a technical standpoint there are a number of potential benefits from off-site manufacture. The extensive use of jigs and templates should provide greater accuracy and tolerances, which in turn can lead to lower wastage of material because more components can be ordered cut to size. Wastage will also be reduced because the construction process is sheltered from the weather and better facilities for storage of materials leads to less damage and theft. The controlled conditions within a factory mean better quality of finish and fewer defects can be achieved. Services can be tested within the factory prior to the units being despatched, leading to lower latent defects.

All of the above could be achieved on a conventional building site with the right workforce and site management, but there is one potential advantage that some manufactured systems would have that would not be available with conventional masonry construction. Because of the way some framed systems are put together it is

quite feasible for them to withstand some tensile forces which masonry would not. Situations where this would be an advantage are in cantilevered structures and in situations where subsidence might be a problem. There are also social benefits to prefabrication. Because much of the construction is undertaken in the factory there is less activity on the construction site leading to a number of benefits for the local environment adjacent to the site where the development is taking place. These include:

- Shorter build times
- Less noise and dust
- Fewer tradesmen visiting the site thus reducing local disruption from parking and pollution.

In addition the establishment of factories creates employment which has a beneficial impact on the local economy. Because the factories can be located anywhere with access to the road network, they can be established where unemployment is greatest. Lower wastage of materials leads to lower volumes of material going to landfill. Many would argue that factory assembly leads to jobs being lost in the vicinity of the site, and much higher overall levels of pollution because of the need to transport the finished units by road. However, both these views are simplifications of complex issues. It may be that less local labour is used on a site, but this is far from certain. In many cases, because of skills shortages, local labour is not available in the right quantity and at the right time, and the work is therefore carried out by operatives who travel some distance to the site. It is also questionable whether the jobs created by using only local labour would be permanent.

Transport is also a contentious issue. Because many workers travel quite long distances to a conventional site the fuel used during many journeys undertaken in smaller cars and vans can easily equate to the relatively few journeys undertaken by large lorries delivering the units. Workers in a factory would in general live nearby, so the impact from fuel use would be less. Working conditions in factories tend to be better than on a construction site leading to both health and safety benefits and greater incentive for employers to invest in staff training because the workforce will be local and therefore be more easily retained.

There are also drawbacks to off-site assembly, the most commonly quoted of which is cost. For example at the moment capital cost of manufactured housing tends to be higher than conventional masonry construction, and usually requires a minimum number of units through the factory in one batch (40 is often quoted as a typical viable threshold). This, though, does not take into account the future maintenance costs. For private sector developers maintenance is not their problem (although it may be a selling point if they were confident of the benefits), whereas for a housing association whole life costs may be a legitimate way of approaching the issue of cost.

There are also developments in computing that offer the possibility of linking the production and assembly line to CAD software. In the future this could enable one-off dwellings and building to be produced for the same unit cost as a production run. The use of RFID technology would enable such production and allow improvements in the entire manufacturing process, delivering and installation of prefabricated components. Another disadvantage often quoted is the fact that with factory production the design needs to be finalised in much more detail well in advance, so that material and components can be ordered and stocked at the factory ready for use. The latter point means that factories are very dependent on the supply chain.

Future maintenance is also a potential problem for manufactured building. Inevitably some specialised components and materials will be used during the manufacturing process. These materials may not be available decades after the dwelling is manufactured, which could prove problematic from a maintenance viewpoint. This raises the issue of standardisation of key components and/or dimensions – something the industry ought to be addressing now. It is also the case that, because specialised materials are used the maintenance requirements for manufactured buildings will differ from that required by conventional masonry housing and building. This too is something that manufacturers should be addressing, perhaps in the form of a user manual.

Types of off-site production

In the UK, there are three principal approaches to off-site production of dwellings using construction.
These are:

- Volumetric
- Panellised
- Semi-volumetric (or hybrid)

Volumetric systems

Volumetric construction (frequently referred to as modular construction) involves the production of three-dimensional units in controlled factory conditions prior to transportation to site. Modules can be brought to site with all internal and external finishes, services and even furnishings installed, ready for assembly. A family-sized dwelling will typically be manufactured in four modules plus roof module(s). Volumetric has many benefits over other forms of construction including improved quality, reduced defects and snagging on-site, rapid assembly, less disruption on-site, better working conditions, increased predictability and control, and efficiency in the production process with the potential benefits of economies of scale. This approach is particularly suited to highly serviced areas such as kitchens and bathrooms, which have a high added value, and cause disruption and delays on-site, but may not necessarily be appropriate for other rooms which have less internal fit-out.

The maximum size of a volumetric unit is determined by the practical problems associated with transportation by road and site access. The factories operate most efficiently when a large number of similar units are made to the same dimensions. Both of these factors work to reduce flexibility in layout and design. For these reasons most volumetric construction in the UK to date has been in the hotels, student and keyworker accommodation, hospitals and fast food sectors, where repetition of units is possible. In addition, the strength and rigidity of the units must be sufficient to allow them to be transported and craned into place on-site without being damaged. The strength requirements for the lifting operation may exceed those for in-use service – thus the structure may have additional members that are not required for its end-use, which can be regarded as inefficient use of materials. Summary of features of volumetric construction

- Most suited for buildings with repeatable cellular units.
- Maximum economy is achieved when modules are standardised.
- Use of a standard library of components reduces costs.
- Transport of units and access to site should be considered

- Most beneficial when used for highly serviced, high value-added areas.
- Construction process on-site can be very short.
- High quality is readily achievable.
- Suitable for extensions to existing buildings, including rooftop extensions.
- Suitable for sites where disruption has to be minimised

Panellised systems

Flat panel units are produced in a factory, and assembled on-site to produce the three dimensional structure. The most common approach is to use open panels, or frames, which consist of a skeletal structure only with services, insulation, external cladding and internal finishing occurring on-site. More complex panels – typically referred to as closed panels – involve more factory-based fabrication and include lining materials and insulation. These can sometimes also include services, windows and doors, internal wall finishes, and external claddings.

Panellised systems are more flexible and generally can more easily accommodate variations in unit plan and detail design than volumetric systems. Spaces such as bedrooms and living spaces lend themselves to panel construction systems, providing greater choice to the client and designer, with fewer restrictions on room size and layout. Furthermore, panellised systems can be stacked flat, which leads to more efficient transportation to site. However, when compared to volumetric the levels of finish and services, which it is practical to install into panels prior to shipping to site, are reduced compared to volumetric. This may not be much of a problem for plain walling but would be a disadvantage for highly serviced areas such as kitchens and bathrooms. Also, there is a greater likelihood of damage to factory-applied finishes either during transportation or assembly on-site. The main features of panellised construction can be summarised as:

- Providing a factory made kit of parts delivered to site for fast on-site erection to form the building shape.
- For maximum economy the panels should follow a common set of design and sizing, from which the building can be formed.
- Use of a standard library of components will reduce costs.
- The amount of on-site finishing required varies depending on the amount of factory finishing applied to the panel.

Semi-volumetric or Hybrid systems

A third option which maximises the benefits from off-site production is to combine the benefits of volumetric and panel construction. Volumetric units can be used for the highly serviced and more readily repeatable areas such as kitchens and bathrooms, with the remainder of the dwelling constructed using panels. This offers the opportunity of bringing together the benefits of each system, and addresses the issues of providing flexibility and consumer choice.

Transport is reduced compared to volumetric construction yet the quality of off-site manufacture is maintained for the high value added areas. Such an approach may provide benefits from economies of scale and the economies of scope, by combining the benefits of mass production, factory production and standardisation with flexibility of options offering customisation. A kit of parts can be used to provide flexibility yet

maintain the benefits of standardisation. Semi-volumetric/hybrid construction is focused on:

- Providing the benefits of volumetric construction for serviced areas and panellised forms for greater flexibility of building layout and reduced transport costs.
- For maximum economy the panels and volumetric units follow a common set of design and sizing.
- Use of a standard library of components will reduce costs.
- On-site finishing requirements vary with the amount of factory finishing applied to the panellised units.
- Services can be concentrated in the volumetric units.
- Site assembly procedures must be carefully considered.

When deciding on the most appropriate construction system for a particular scheme there are many issues to be considered, which can be separated into two categories. The first is a set of broad issues that must be balanced against each other such as design goals, impact on procurement and construction processes and client requirements. The second is a set of key attributes that vary from system to system. Both are considered in more detail in the sections.

Balancing the issues

Below is a list of key issues:

- **Time scale** – design time available and site programme constraints
- **Procurement** – What management skills are available
- **Design impact** – Complexity of the design and defined fixed needs
- **Construction process impacts** – Site location for deliveries and use of machinery etc
- **Sustainability** impact and importance
- **Value for money**

An understanding of the key issues relevant to each approach is needed before the appropriate solution can be matched to the project goals.

Time scale comparisons

In general terms, as the level of prefabrication increases so design decisions are moved forward in the process leading to a longer design phase, but the time spent on-site for the assembly process is shortened. A particular feature of off-site manufacture is that the design has to be frozen at an earlier stage to allow for efficient manufacture to proceed. Thus, late changes can be costly, difficult to accommodate and disruptive. Semi-volumetric construction requires this aspect to be addressed on the volumetric elements at a different time period than the remaining building.

Impact on procurement and design processes

For the full benefits of off-site manufacture to be realised, the implications of using this technology must be considered throughout the procurement process from initial briefing

stages and site selection to the management of the design and construction processes. Decisions made during the early stages can be critical to the overall success of the project, so project briefs should be integrated into the procurement process from the outset. As with all methods of procurement, mechanisms should be included for anticipating and managing external risks that may adversely affect the programme of work or cost. However, risk should be borne by those most able to manage them.

The typical procurement process for an off-site manufactured building reflects the aims of the Egan report 'Rethinking Construction' which highlights the benefits of prefabrication and partnering between suppliers and clients. The benefits of off-site manufacture will be maximised only if client, designer, manufacturer and the supply chain work in partnership at all phases of the project. Successful partnering requires considerable 'up front' investment of time and resources by all concerned, and time will need to be allowed for that. The spirit of collaboration and trust that goes with true partnering can pay dividends in terms of the quality of the finished project and reduced defects, and even greater benefits can be realised by partnering over a series of projects. The decision making process for off-site manufacture varies from that for traditional construction because of:

- The involvement of additional parties – the manufacturer of the prefabricated units, the materials and components suppliers and the specialist on-site assembly team – in the design, costing and logistics.
- The need to make key decisions early in the procurement process.
- The effect of transportation on the approach adopted and the logistics and costs.
- Differences in the construction process on-site.

Other issues relating to the supply side include the use of products and materials not normally used on-site-based construction, and which therefore need to be ordered specially for the job. Also, product substitution is not usually an issue on conventional sites but may lead to unforeseen problems in the factory. All these issues need to be addressed well in advance of commencement in the factory.

Impact on construction process

Management of the process of assembling off-site manufactured components on-site is crucial to the success of such a project. Careful consideration is required of:

- Better control of the manufacturing process
- Transport and delivery scheduling
- Unloading and storage of units on-site
- Prevention of damage during transport, delivery, erection and subsequent works
- Interfaces between off-site manufactured components and site works
- The efficient use of plant (cranes, scaffolding, etc)

It is crucial that units are delivered in the right sequence and when the site is ready to take delivery of them, particularly if storage facilities are limited. It is much better to store unwanted units at the factory rather than on-site, but that would have clear knock-on effects at the factory which need to be fully explored with the manufacturer as part of the early project planning.

Many issues have arisen related to the interface between different parts of the construction process. For example, it would not be unusual for masonry construction to accommodate a variation of 25 mm or more in the level of the foundations, but this would

present severe problems for panellised and volumetric construction. Early discussion with the manufacturers and the groundworks contractor should avoid the problem. Consideration should also be given to the use of engineered foundations.

Scaffolding is also an issue that has caused many problems with off-site manufactured construction. A number of failed attempts have been made to build without the need for scaffolding, leading to disruption of the programme when the scaffolding was finally erected. It is possible to construct without scaffolding, but because of logistical and health and safety issues it would be wise to undertake a risk analysis in advance. There is a need for careful consideration of who controls the site process, particularly during unloading and erection of off-site manufactured components. Site managers with the necessary project management skills who are conversant with the type of technology being used are needed. Manufacturers have operatives experienced in the process of assembling their own components and systems, and these individuals are increasingly being used to good effect to manage the assembly process on-site.

Sustainability considerations

Sustainable construction has many facets, it is quite feasible for many of the construction technologies available score well against any of these facets For example it is possible to build with low material wastage using any technology. However, conditions on a building site mean that for any given operation there is usually a higher rate of wastage in that environment than if the same operation were undertaken in factory conditions. Thus, the higher the proportion of work undertaken in a factory the lower the materials wastage will tend to be.

Transport is one area where manufactured prefabricated buildings is frequently criticised because of the need to transport large units by road. This, too, is a very complex area prone to oversimplification. It is true that large lorries must often travel quite long distances to deliver manufactured building, and that process would consume a lot of fuel, which would not be used with conventional construction. However, a conventional site would normally use a considerable amount of fuel for plant and machinery, which would not be used in a factory, and operatives on conventional construction sites drive, on average, much greater distances to their workplace compared to factory workers. Thus if all fuel usage is taken into account the picture is much less clear cut.

Costs/value for money

The cost of a project can vary considerably, and in particular is sensitive to location and design. Costs for off-site manufactured housing are much more sensitive to the number of units being produced than conventional construction, and also depend heavily on the ease with which subsequent site-based operations (such as assembly and any remaining fit-out) can be carried out (i.e. the cost is greatly influenced by how well the units have been designed for both manufacture and assembly).
best value for money.

Whole life costs for the structure and components, factoring in likely maintenance costs and replacement costs for equipment and services, are potentially much more important than initial capital costs. Also relevant to the housing associations, schools and hospitals built under the government PFI scheme is how quickly building be used. Thus any premiums for low volume orders can potentially pay back in terms of speed on-site and

increased reliability of the product. Cost comparisons are also dependent on the labour market for on-site workers, particularly the lack of traditional site skilled trades people.

Construction process

Interface between site and factory

The interface between activities in the factory and the site are key to a successful project. The off-site manufacturer and site contractor must establish an understanding of their respective requirements.

Damage from follow on trades to off-site manufactured components must be minimised. Finished areas such as volumetric units should not be accessible to tradesmen on-site and should ideally be locked. In particular, they should not form routes through which tradesmen and materials must pass.

Transport and access

Sizes of components that can be delivered to site for assembly are limited principally by transport and access requirements. The maximum width for an unaccompanied load in the *UK is 2.9 m (this can be increased to 4.3 m with a police escort)*. Arrangements on-site for a planned delivery of components as they are required is important for site management, particularly on small sites or sites with restricted access. Components should be suitably weather protected during transport and during any storage and erection period on-site. Where volumetric systems are used it is important that water ingress is prevented during any period before the roof is installed.

Site management – who controls the process

Off-site manufactured projects require good site management for the benefits to be realised. Many manufacturers have experts to manage the erection process. It may be appropriate to have different managers controlling different parts of the process, so a substructure company manages the site during ground works, the modular manufacturer control the site during assembly of modules, a cladding expert provides site management during the cladding phase, etc. In some cases the off-site manufacturer has taken on the management of the whole building process.

Speed

Potentially, there are significant benefits from reduced time on-site which can reduce costs and disruption. This has to be balanced by the likelihood of a longer lead in time for design and manufacture. Successful projects need 'up front ' time and resources. Objectives must be established and clearly defined at the outset and the design process carefully managed.

Health and Safety

Health and Safety issues are pushing many house builders towards off-site manufacturing, as much of the process can be removed from site into more controlled conditions. There is potential to significantly reduce or eliminate scaffolding.

Training

The knowledge base about off-site manufacture is limited in the UK and mainly resides with the manufacturers and a few experts. Exchange of personnel between site and factory can be invaluable to the understanding of different parts of the process.

2 Summary of Impact of the Technology in other Sectors

The examples given are from a previous ICT Carrier report (ref) show that the nuclear, parcel and automotive industries have played a leading role in integrating their supply chain, in particular in the distribution and tracking of goods and components, using tagging and wireless technologies. Those who adopted the technology have benefited significantly:

- Accurate delivery of almost 100% of parcels has been shown in parcel industry, with potential annual savings running in excess of £100K. Achieving this on a construction site will significantly reduce cost of disputes, improve efficiency, profitability and reduce litigation.
- Cost of implementing the system was recouped by the Lynx group in 8 months
- The parcel industry has shown that using these technologies the efficiency of distribution centres has improved by 400%. The throughput of parcels per hour has increased from 3000 per hour to 40,000 per hour as a result of using tagging technology.
- An existing ICT Carrier project is implementing tagging application at four construction manufacturers (door, steel frames, concrete precast manufacturers) for improving the manufacturing process. The initial feedback from these manufacturers is that the technology will improve their manufacturing process significantly and allow them to offer customers added value service. The door manufacturer has calculated that if a complete RFID solution was implemented at all the stages of manufacturing the likely saving would account to between 2-5% of turnover.
- The oil industry has used tags to reduce the cycle for repairing safety relief valves by 64%. They have also used tags for monitor, inspect and repair pipe joints, ensuring that the correct repair inspection procedure and correct repair technique are used. Tags have been used for 100% accuracy and assurance that corrects safety equipment is in the correct location and set at the correct levels.
- Internet visibility of orders for customer from order to site delivery or installation.
- Tagging components and the data they provide has proved essential for lean production in the automotive industry.

The competitiveness of the industries involved will increase significantly, in particular the absence of similar practices in other countries, provides a unique opportunity to increasing exports.

3 Application of ICT technology to off site construction construction manufacturers products and supply chain

Applications of ICT technology to improve the logistics of the construction industry

A BRE logistics study (Ref 3) stated that the use of ICT is in its infancy within the construction industry and in particular in the logistics of goods and materials and there is considerable scope for improvement. ICT technologies are essential in improving the entire supply chain.

One of the most striking observations from the BRE logistics project was that constructions sites did not have in place any systems (whether paper based or computer based) at main contractor level for the tracking and control of materials. There was almost no data available which gave any information on the quantities, values or locations of material on site or in any other part of the supply chain. The only data which was captured and which could be considered relevant in supply chain management terms was the individual supplier delivery notes used by the sub-contractors, all of which were available only on paper.

The study emphasised that the construction industry needs to understand, that the ICT requirements for improvement in the logistics of any business are:

- ⇒ Data management - for logistics processes accurate information and standard codes is required for each component used in the business, which will eventually be part of the good service.
- ⇒ Materials management - Controlling goods and materials movement and traceability of related information require IT systems and data that are mapped to the supply chain processes.
- ⇒ Information accessibility - The above information should be easily accessible by the supply chain participants.
- ⇒ Schedule management

The main conclusion of the study was that ICT technology solutions listed below are required to improve the construction logistic supply chain in order to improve the construction industries competitiveness in line with government goals set for the industry.

- Development of a paperless delivery and invoicing system, providing a clear audit trial
- The use of existing ICT technologies implemented to track components through design, manufacture, site location, installation and in use in order to identify whole life cost and functional and performance indicators,
- The construction industry needs to learn from other sectors, particularly the use of ICT, in developing "just in time" scheduled manufacturing approach.

Applications for the off site manufacturing

Although there are a number of potential uses of RFID in off site manufacturing, at present the following are thought to offer most potential:

- Paperless Invoicing and Ordering System

- Inventory Control
- Stock control
- Project monitoring - correlating manpower used with tasks performed
- Project monitoring - correlating use of equipment resources with tasks performed
- Manufacturing process control through centralised tracking and resource allocation
- Erection tracking
- Maintenance
- Demolition and disposal (end of product life)
- Dispute Resolution

Tracking the Installation of building components

The use of tags during installation of construction products, such as bath pods on site would be an extension of the factory operation, where tagging is used as an integral part of the production system. A handheld device linked to the internet, with a built in tag reader, on site could be used to confirm receipt of components, report on installation progress and confirm hand over status. In a further development, progress monitoring would come to life with a graphic display on an integrated site monitor; it could show the model being completed, either by adding each component as it is installed or alternatively changing the colour of the components on the full model for delivery, installation and hand over.

Installation tracking will be seen as a corollary to Centralised Tracking and Resource Allocation, and the enhanced information flow could be very beneficial, particularly in integrated or partnering contracts. The system developed for tracking installation of building components can also be used to monitor the work completed by contractors on site, which can then feed into a central resource and planning schedule of work.

Dispute resolution

One of the problems that off site manufacturers face is with the installation of the wrong components in a building. Tags incorporated into the components could store information on the exact location where the components is to be installed in the building, to prevent costly disputes.

Asset management and tracking of assets

The tags incorporated into off site manufactured components can be used by most asset management systems. There already are asset management systems, which allow tracking of assets using barcode. Using e-tags will add flexibility, and where appropriate the information on the tag can be updated throughout the life of an asset. Barcodes cannot be used for such items as they will be easily destroyed or vandalised. The tags with an internet enabled scanner could provide additional information in real time, such that the basic health and safety requirements, maintenance inspection notes etc, can be downloaded from the internet And records all linked with specific building components.

Application to maintenance of building services systems

As an extension to the Asset Management application, as demonstrated in one of the example case studies described above, tags could be used to store and regularly update specification and performance information for equipment, plant, distribution system, fire alarm system, etc. In particular the maintenance schedules could easily be put into the tags providing the maintenance workers a clear indication whether a piece of equipment needs to be replaced or overhauled.

Deconstruction of buildings

The safe deconstruction and disposal of off site manufactured components would be helped if tags incorporated within the component carry the appropriate information or provide a web link with this information.

4 Barriers to the use of tagging and wireless technology applications in construction

Ten leading manufacturers, contractors and clients were interviewed to ascertain a snap shot of possible barriers to the uptake of the tagging and related wireless technologies. The results obtained are summarised below.

- Most companies see advantage in using tagging and wireless applications in improving their business.
- All the companies would implement these technologies if commercial benefits could be shown on demonstration projects or their competitors were using it.
- The main driver for companies to implement tagging and wireless technology in their business was profitability.
- Most companies wanted at least savings of 1% on turnover and a return on investment within 1-2 years.
- The main areas identified for using tagging and wireless technology were: for delivery tracking and a paperless invoice note. Other areas of interest were asset management, dispute resolution, location of items on site and added service to clients.

Barriers to the uptake of tagging and wireless technologies in construction

The results of the interview highlighted the main barriers to the uptake of these technologies are as follows:

- Lack of knowledge of the technologies and their potential applications i.e. thinking out of the boxes
- Lack of real construction demonstration projects showing potential savings and efficiency to the industry. Three of the companies interviewed were aware of the existing ICT Carrier project Tag and Track, but unaware of the results of the project.

5 Areas of improvement within the off site manufacturers supply chain

ICT technologies will have a major role in improving the efficiency and productivity of the off site manufacturing sector. The main IT development in the recent years within the construction sector supply chain has been the development of electronic projects management. There are many organisations offering on line collaboration and knowledge management to the construction industry. However, most of these services, while a welcome start are no more than document management. The use of IT in the supply chain activities and processes and the link to production and operation is almost non-existent. The nature of the construction projects, which is a temporary enterprise of different firms, disciplines and trades, sometimes with conflict or little regard for each others interests, requires that new ways of working, cultural and technological solutions be found and that the benefits of these must have been proven for these new practices to be taken up.

Previous BRE and ICT Carrier reports have identified that electronic tagging, handheld devices, and wireless technologies will have a significant role in improving the construction industry supply chain. As previously mentioned above, these technologies have been successfully used in other industrial sectors. Similar improvements are possible within the off site manufacturing sector.

Tables 1 and 2 below summarise areas where the off site manufacturing supply chain can be improved using RFID and related technologies.

Table 1- Summary of areas where the off site manufacturing supply chain can be improved and its impact on disciplines involved

Areas of improvements in the supply chain	Designer	Manufacturer	Contractor (Main/sub)	Facility Management	Building Owner
Tracking manufacturing process in real time	λ	λ	λ	λ	
Producing mass bespoke components in the timescale and cost of mass produced components		λ			
Tracking delivery of goods		λ	λ	λ	
Paperless invoicing system		λ	λ	λ	λ
Internet visible ordering and delivery service	λ	λ	λ	λ	
Locating materials in the factory and on site		λ	λ	λ	
Providing up to date information on site for a tagged building product, e.g. on Health and Safety, installation, etc	λ	λ	λ	λ	λ
Maintenance of building services and assets	λ	λ	λ	λ	λ
Aid in integrating supply chain	λ	λ	λ	λ	λ
Dispute Resolution		λ	λ	λ	

Table 2- Summary of areas where the off site manufacturing supply chain can be improved using different ICT technologies and possible benefits

Areas of improvements in the supply chain	Wireless Technology	Tags/ bar codes	Handhed devices	Web application	GPS	Benefits of technology
Tracking manufacturing process In real time	λ	λ	λ	λ		More efficient, effective, and profitable processes
Producing mass bespoke components in the timescale and cost of mass produced components	λ	λ	λ	λ		More efficient, effective and profitable processes. Allow expansion of product range.
Tracking delivery of goods	λ	λ	λ	λ	λ	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	λ	λ	λ	λ	λ	
Internet visible ordering and delivery service	λ	λ	λ	λ		
Asset Management	λ	λ	λ	λ	λ	More efficient, effective, and profitable processes
Locating material in the factory and on site	λ	λ	λ		λ	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	λ	λ	λ	λ		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

Areas of improvements in the supply chain	Wireless Technology	Tags/ bar codes	Handhed devices	Web application	GPS	Benefits of technology
Maintenance of building services and assets	λ	λ		λ		Allow better monitoring of operatives and maintenance scheduling. Reduce maintenance inspection times With increased bandwidth wireless technology to be used to download data required by operatives in real time and improve efficiency, accuracy and reduce number of visits
Facility/Asset Management	λ	λ		λ	λ	
Aid in integrating supply chain	λ	λ		λ	λ	All the above

Our analysis of the needs of the industry and barriers to the take up of technology shows that the main area where ICT technology will have the most immediate impact is improving the manufacturing process and logistics within the supply chain and the development of a paperless invoicing system. This is discussed in the next section.

6 Forecast Impact on the Off Site Manufacturing Sector

The UK construction industry accounts for 10% GDP of the UK i.e. approximately £100 billion per year. One third of this is accounted for by manufacturing i.e. £30 billion, and construction manufacturing accounts for 20% of the UK manufacturing base. One tenth of construction manufacturing i.e. £3 billion is accounted for by off site manufacturing. The manufacturing of precast concrete elements is also classified as off site manufacturing and according to the British Precast Concrete Federation its annual turnover is £1.6 billion. The annual growth of this sector is in the order of 18-20% per year and many of leading experts in the field believe that within several years the off site construction sector will have a turnover of £30 billon per year i.e. 6% of the UK manufacturing base. The off site manufacturing sector is seen as a sunrise industry, which is essential if various government targets on housing, health and education are to be met.

It has not, however, benefited from recent developments in IT as much as similar sectors. One of the key areas where costs can be reduced is the procurement of products for construction, manufacturing process and their delivery. Advanced technology is not currently used to track components through design, manufacture, procurement and installation of construction products. The use of information technology and electronics within this sector offers potential improvements in quality, cost savings in production and delivery of building components to the manufacturer and their customers in the construction industry. The sector can learn from the ICT used in the parcel, oil, retail industries and the trials currently underway in construction in integrating their supply chain, particularly the logistics. Reasons why these sectors have made significant progress compared to the construction industry include:

- They have invested more in Information Technology than the construction industry-construction industry spends around £500/head which is five times lower than the lowest in these sectors)
- There are large companies in these sectors that have significant influence over their suppliers
- They tend to have long term relationships with their suppliers
- They use IT to improve their efficiency and the services they provide to their customers

This has not been the case within the construction industry, however as mentioned above this is set to improve as result of recommendations by the Sir John Egan report.

- Off site manufacturers are now developing more long term relationships with their supply chain, including leading clients and contractors.
- All the partners in a construction project are now being encouraged to take part right from the inception and design phases of the project.
- RFID technology allows the possibility of producing bespoke components of site at the same cost of mass produced units.

Conditions are therefore now conducive and very timely for technology transfer from other industries to the off site manufacturing sector and their supply chain.

On the basis of the evidence of savings and efficiency improvements in other industrial sectors and the limited trails undertaken in construction, it is envisaged that if ICT were applied to the manufacturing, logistics of manufactured products and installation, the cost

savings to an off site manufacturer would be in the region of 1-3% cost savings resulting from improved inventory, manufacturing process, stock control, delivery of correct product and installation. Hazlin of Ludlow, a door manufacturer involved in a DTI ICT Carrier RFID project "Tag and Track", has estimated if RFID application was applied throughout its manufacturing and logistic process it would save between 2-5% per year.

It is estimated that the adoption of the technology by UK off site manufacturers supplying to the construction industry within the next 5 years could lead to annual savings in the order of £10m to £30m. Another significant tangible and intangible benefit would be reduction in litigation costs which normally occur mainly due to lack of delivery records and mismatch of specifications with delivered goods.

The technology also offer the opportunity to produced high value bespoke components within the same time scale and cost of mass produced components. Hazlin of Ludlow produces bespoke high value fire doors and have identified that it is feasible to use RFID technology to convert the production of these doors to exactly like mass produced doors i.e. no one door on the production line is the same. The RFID tags in the door are read by the appropriate machine or operative using a tag reader, which instructs them on the operation to be performed. In the case of machines the integration of RFID technology will automate the whole process. Hazlin has estimated that the automation of the cutting operation of the door by their route can save them over 600 minutes a week and reduces the reliance on the few machine operators for the router. Similar applications of RFID technology can be extended to the off site manufacturing sector and if this was to happen this would allow the sector to offer a much wider rage of products and lead to further growth in the sector.

Another benefit of improve tracking is that it will reduce the litigation costs that the industry incurs every year, which are in excess of £250 million annual, by providing a clear audit trail of materials delivered to site. Consequently, disputes arrange on lost invoice and whether goods have been delivered should be eliminated benefiting all parties in the construction supply chain. Bovis Landless estimates that £15,000 is spent on disputes arising from lost invoice receipts per average construction site. Thus the potential savings from the elimination of legal disputes arising from lost invoices or whether a material has been delivered for every 1000 sites is £1.5 million annual.

Other Socio-Economic Benefits

The use of electronic tagging and wireless technologies will also have invisible and cultural impacts. These include:

- improved transparency in delivery of goods from manufacture to site,
- reduced disputes between suppliers of products and buyers which in many cases lead to litigation,
- improves the adversarial culture prevalent in construction process amongst the supply chain,
- potential to improve health and safety on site, during maintenance and decommissioning of building and its components.

7 Recommendations and the way forward

The study of barriers to take up on the new RFID technologies has shown that the following are the main reasons for the industry failing to adopt the proposed technologies:

- Lack of awareness of the technology and its applicability to manufacturers' product and supply chain. The technology is relatively new and most firms contacted were not aware of its existence and applicability/relevance to their businesses.
- Lack of hard evidence that the technology works. Most firms expect a return on investment within 1 to 2 years.
- Fear of unaffordable set up costs and disruption to business as usual. Firms are reluctant to adopt new technologies that require major changes to their current manufacturing process.

The companies interviewed have shown that all of them would adopt the new technology if its benefits could be demonstrated on a demonstration project.

Unlike the nuclear and automotive industries, the project's target sector firms are too small and fragmented to move all its members in a harmonious way. It is only through the demonstration of benefits to the members of the supply chain that they may be encouraged to adopt new processes and technology.

The main recommendation is that demonstration projects showing the commercial benefits of using tagging and wireless technologies for improving the off site manufacturing supply chain for a range of products should be undertaken. In order to make the demonstration projects effective and achieve their aims there needs to be buy in from the industry so that addressing serious issues regarding these technologies, such as standard codes for construction products, are universal accepted and adopted by industry. This can be achieved if the projects involve the top ten contractors, which account for 25% of construction turnover, large builders' merchants and large building owners as will as the suppliers. This will encourage the uptake of the technology coupled with an effective dissemination strategy.

8 Conclusions

The use of tagging and wireless applications in the parcel industry, nuclear industry and in schools, and the limited trials in the construction industry shows that the adoption of these technologies by the construction industry has the potential to improve the constriction process with tangible improvements in efficiency and profitability in the sector.

It is estimated that the adoption of the technology by the off site manufacturing sector within the next 5 years could lead to savings in the order of up to £30m per annum and a significant reduction in litigation costs. It will also allow the possibility of producing bespoke components at the same scale and cost of mass produced units for the sector. If this was to happen this would allow the sector to offer a much wider rage of products and lead to further growth in the sector.

The benefits both to manufacturers and their clients extend far beyond the procurement and delivery stage. For example, the tags and information linked to databases will have major benefits downstream the supply chain and the maintenance, re-ordering of correct parts, health and safety in operation and safe disposal of products will also be significantly improved. The application of technology can also be extended to the design and manufacture of products and the upstream supply chain with similarly significant benefits.

However, the study has shown that the awareness within the target sector of the proposed technology is very low. For this reason it is recommended one specific aspect of the supply chain, i.e. procurement and delivery of products to construction sites and the flow of information within this part of the supply chain, is shown to demonstrate tangible and quantitative benefits of using tagging and wireless technology.

A survey carried out under this scoping study has shown that 100% of firms surveyed would adopt the new technology if its benefits could be demonstrated in a demonstration project.

The main recommendation of this scoping study is that demonstration projects should be undertaken showing the commercial benefits of using these technologies for improving the logistics within the supply chain for a range of construction products. Coupled with an effective dissemination strategy this will encourage the uptake of the technology.

Reference

1. 'Constructing the Team' (*Latham M., 1994, HMSO, London)*
2. 'Rethinking Construction'
   (Egan J., 1998. Report of the Construction Task Force, Department of Environment, Transport and the Regions, London
3. Technology Review DTI report, June 2001
4. Improving the Construction Demand Chain DTI report, June 2001