Offsite Production in the UK Construction Industry – prepared by HSE

A Brief Overview

Report Prepared by Stephen Taylor: Construction Engineering Specialist Team: HSE

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Off-Site Construction in the UK Building Industry- A Brief Overview

This paper discusses the historical and current application of modern methods of construction using off-site production techniques. The paper gives an overview of the various types of off-site construction; specific case studies illustrating current practice; and, the primary benefits to health and safety on construction sites through its implementation.

This brief history and overview owes much of its content to efforts by others notably members of the Buildoffsite team such as Loughborough University, The Steel Construction Institute, TRADA and the Building Research Establishment. Without their efforts during the last 10 years there would be little understanding of how this important part of the UK construction Industry is structured and where its utilisation can be most beneficial.

Photograph courtesy of Corus Living Solutions PLC

Off-Site Construction in the UK Building Industry- A Brief Overview

Historical Perspective

The end of World War One saw the United Kingdom construction industry affected by major shortages of skilled labour and building materials - both having been diverted into the war effort. The result was an acute shortage of housing. This shortage stimulated a search for new methods of construction that would alleviate this problem.

Between 1918 and 1939 over 20 steel-framed housing systems along with various types of housing based on traditional insitu and precast concrete, timber and occasionally cast iron building methods were developed.

Over this period 4.5 million houses were built but only around 5% were constructed using new methods of construction. The majority of houses were still traditionally built as labour and materials became less scarce.

In Scotland there was also a need to build new homes. A need that could not be satisfied using traditional building methods mainly due to a shortage of good quality bricks, a lack of bricklayers and the rising costs of stone and slate. This forced the need to build substantially more houses using alternative methods of construction compared to the south.

World War 2

The end of the World War Two saw a new approach for the construction of new dwellings. In addition to replacing houses destroyed during the war, the Government in1945 published a white paper with objectives to complete the slum clearance programme started in the 1930's.

The emphasis was to supplement traditional building operations with methods of construction using industrial capacity outside of the building industry. Immediately after the war there was a surplus of steel and aluminium production from industries geared to war output and now requiring diversification to survive. These factors drove the industry towards prefabrication and resulted in many varieties of concrete, timber, steel and hybrid framed systems.

Industrialised Buildings

Throughout the 1950's and 1960's the UK building industry moved towards industrialised forms of building. However, while those who were promoting industrialised building methods with an ever growing confidence, those who lived in these houses remained suspicious about modern methods of construction, in particular high-rise building – suspicions that heightened with the collapse of Ronan Point and other problems associated with large panel high-rise buildings.

Industrialised building

Industrialised building is based on the principal that as much of the work is done in a factory environment leaving simple assembly operations to take place on site. Industrialised building takes two forms: closed and open. Closed construction has much of the structure made from a fixed set of prefabricated parts. Open construction produces a shell from a small number of parts allowing the designer to create a unique design and substitute products from other manufacturers.

Many industrialised building systems employ large panel methods of construction using factory made pre-cast concrete floor and wall panels. Units arrive on site in their assembly sequence and then assembled with the aid of a crane.

Another generic form of construction used during the 1960's and 70's was volumetric construction involving the production of buildings as a number of boxes connected on site - usually involving lightweight frame construction in timber or steel.

Pioneering volumetric units during the 1940's were made up of 4 aluminium-framed units one of which contained the entire plumbing. These were later superseded by aluminium panellised construction. These units pioneered the principle of bathroom and kitchen service cores.

During the 1960's a simplification of the design process produced Rationalised Traditional Construction

Rational Traditional Construction

This used masonry cross-wall construction with the front and rear elevations in-filled with storey height timber framed panels. All dimensions and details were standardised with all joists cut to a standard length and eaves details suitable for a range of external wall designs

Steel, timber and concrete framed systems continued development into the early 1980's. Prefabricated housing became dominated by timber frame systems using storey height timber wall panels to the inner leaf, timber floor panels and an outer leaf of brick or

stone. Timber framed dwellings grew to around 30% of the new build market but suffered a dramatic downturn after adverse coverage on the World in Action TV programme

World in Action

' World in Action' was severely critical of a small group of timber framed dwellings in the West of England inferring that the construction was not watertight giving rise to rot in the structure. The programme implied that this defect applied to all timber-framed buildings and problems for current owners of this type of construction would occur in the future.

Screened at a time when the 'Right to Buy' scheme was being promoted and when many public sector houses were built in timber frame construction there was a significant down-turn in the number of houses sold.

Over 400 houses were independently surveyed in areas of severe exposure and found no evidence of decay that supported the projections made in the programme. The programme is still quoted today as a justification for choosing different forms of construction

In Scotland where the traditional building method is stone or timber rather than brick and with an established and respected timber frame tradition the market for this type of construction was hardly affected at all.

With the 'Rethinking Construction Agenda' the UK construction industry is again experimenting with alternative construction techniques.

Drivers for offsite construction

There is now a shift towards prefabrication through political pressure to construct affordable quality homes and by major problems inherent within the construction industry.

Political initiatives include 'Rethinking Construction' the report of the Construction Task Force (the Egan Report) and the subsequent launch of the Movement for Innovation (M4I) and the Housing Forum.

In the social housing sector the Housing Corporation (HC) have strongly supported the activities of the Task Force and the Housing Forum and require future schemes to be Egan compliant.

Private house builders are looking at prefabrication due to skill shortages coupled with an aging workforce. It is difficult to get skilled workers for conventional sites as younger people no longer regard the construction industry as a worthwhile career through its poor image and poor working conditions.

Ongoing reviews of Building Regulations - particularly the requirements for thermal and acoustic performance - are setting more onerous criteria for performance requirements and the testing regimes of the finished dwelling.

M^{4}I and the Housing Forum

The Movement for Innovation was launched in 1998 to facilitate cultural change in the UK construction Industry identified as necessary by the Egan Report. Four priorities were identified:

- product development;
- project implementation;
- partnering the supply chain; and,
- production of components.

Five drivers for change were identified:

- customer focus;
- committed leadership;
- integration of processes;
- integration of product teams; and,
- commitment to people.

In December 1998 the Housing Forum was launched to promote innovation in the Housing Sector through mechanisms such as key performance indicators, seminars, demonstration projects and the Offsite Manufacturing Working Group.

Good acoustic and thermal performance requirements both need quality workmanship if standards are to be consistent. Offsite construction offers a chance of achieving consistently high standards compared to traditional site-based masonry construction. As regulations become even more onerous and clients see the improvement in quality available from prefabrication an increasing proportion of housing will be built in this way.

The position today

The off site construction of buildings, building elements and structures is currently worth around £2-3 Billion per year and accounts for around 2% of the total construction market – a market share increasing by 25% per year.

Off-site production is fragmented and dominated by relatively small companies with little effective coordination or partnering. Assumptions are still made by those who procure buildings that off-site solutions have failed in the past – the World in Action syndrome - that solutions are aimed only at the housing market and that off site is more expensive than traditional on site methods of construction.

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Clients using off-site production techniques find that many UK manufacturers now use state of the art manufacturing techniques in modern highly automated factories. Benefits include predictability, quality assurance, faster construction times, less waste, less noise and disruption to neighbours, less - even zero - defects and lower site accident rates and improved health and safety.

These advantages are seen clearly in urban locations where the increasing demand for housing and the scarcity of green field sites forces developers to build on ever smaller plots of land within existing residential developments. As more housing is built, so the demand for schools, shops, hospitals, and leisure and infrastructure facilities increases.

The Steel Construction Institute carried out in-depth studies of several construction projects involving various degrees of pre-fabricated steel construction in urban locations. The study identified the benefits of modern methods of construction with particular regard to the disruption caused to local residents from dust, noise and commercial vehicle movements and the environmental impact of site-generated waste. The study looked at three schools and three residential buildings using varying degrees of prefabrication including bare steel panels, insulated infill panels and volumetric modules.

The findings support the view that off-site construction is faster than traditional on-site construction. This was an important factor in the case of the three schools as the building programme was determined by the new school term. In one case this meant cutting the build time from 76 to 54 weeks. All of the sites visited were measurably quieter than traditional construction sites with fewer people working on site.

A similar study carried out by the SCI on a 4-storey residential building estimated that the total amount of site labour could be reduced by as much as 75% through the use of off-site construction - a benefit to the local residents in terms of the general level of site activity and the number of vehicles travelling to and from the site on a daily basis and needing somewhere to park during the day.

An important source of nuisance to local residents is commercial vehicle traffic from deliveries of materials, collection of waste and deliveries and collections of plant. Off site construction reduced the quantity of site-generated waste by the elimination of waste board materials and insulation and the complete elimination of steel off-cuts.

There are many attributes to procuring construction materials, elements of construction and finished buildings away from the place where they will be used. Most are favourable to the adoption of these techniques and include:

- **Reduction in Waste materials**

Factory production lines using CNC machines for accurate cutting, aligning, screwing, nailing, painting and handling etc drastically reduce waste materials. What waste is produced is controlled and recycled.

- **Shorter Build times**

Time on site depends on the amount of factory-produced components and those that are assembled traditionally. Buildings may be constructed from large and small components delivered to site and fabricated by many different trades. Build times are compromised by material and skill shortages and by inclement weather. Buildings that are 100% manufactured in a factory, possibly many hundreds of miles from the site, delivered by road transport and erected on site by crane using skilled assemblers are not subject to these on-site problems. An example of lower site time is that demonstrated by McDonald,s fast food chain where site time from green field to first hamburger sold can be as low as 48 hours site time. Time in a controlled factory production line is almost 4000 hours.

- **Controlled build environment**

Factory controlled conditions mean a better quality of build; better finish; fewer defects; all snagging complete and all services tested. These advantages are matched by those for the skilled workforce who are carrying out the work – a warm, controlled and enclosed workplace using production line techniques that significantly reduce the risk of accidents and ill health.

- **Made to order**

Orders for factory assembled components is not weather dependent. Work is scheduled for specific times on the production line with start and finish not controlled by inclement weather disruptions.

- **Less noise, dust and local disruption**

There can be much annoyance to neighbours caused by traditional building methods usually from noise, dust and litter. With less activity on the construction site the local environment benefits.

- **Fewer workmen on site**

As most of the work has been carried out off site there is a reduced assembly time on site with fewer tradesmen required.

- **Creation of employment in areas away from the building site**

With shortages in locally available skills it is unlikely that traditional construction methods employ local labour. The site workforce may have to travel considerable distances to the site. Employment for factory-produced buildings is easier as the factory site is permanent and skill shortages and numbers can be easily addressed. Local employment will always benefit where permanent factory units are established.

- **Transport from factory to site**

Whatever is constructed in the factory has to be transported to the construction site and is dependent upon the limitations of vehicles and available traffic routes. Modular buildings are limited to the sizes that can be lifted and transported safely to site by lorry.

- **Cost**

Tenders often take no account of the shorter delivery and erection times; and many benefits are negated by following trades using traditional building methods e.g. precast concrete piles and ring beams are manufactured off-site, delivered and erected. Erection time for precast beams can be measured in minutes while following masonry based trades and roofing take weeks to complete. Other savings are made in the reduction of preliminaries, reduced site storage requirements and welfare facilities.

- **Economies of scale**

Factory based systems are not particularly suitable for bespoke one-off buildings and economies of scale are dependant upon large and regular orders. Where bulk orders are procured cost savings are significant and benefit both supplier and manufacturer.

- **Computing and traceability of components**

3D modelling and component scheduling enables a fully completed building to be visualised prior to construction. Changes to the layout can be made quickly and cheaply. Assembly drawings are used by the factory production lines using CNC machines and production methods. As-built drawings and equipment schedules become embedded in the O and M manual making it easy to identify parts for maintenance schedules.

- **Technological**

The use of templates and jigs in a factory environment provides greater accuracy and tolerances particularly when used with CAD design systems.

- **Reduction in accidents and ill health**

Transferring much of the construction programme from an open site to a controlled factory environment reduces on-site time for workers and reduces the potential for site-based accidents and ill health.

While this is highly desirable there must also be serious consideration that any site-based risk is not transferred to the factory or somewhere in-between factory and site.

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'Buildoffsite'

Buildoffsite is an industry-wide campaigning organisation of clients, developers, designers, contractors, manufacturers, suppliers, government, advisors and researchers promoting uptake of offsite construction techniques by UK construction.

Growing demand, coupled with poor build quality and a reducing skills base, has created a dilemma that will not be resolved without a "step change" in productivity and quality of build. Offsite techniques offer a potential solution. Buildoffsite, through initial funding from the DTI promotes this option.

Offsite construction has long been seen as a potential solution to the challenges facing UK construction. The uptake has been limited.

There are many successful companies but the industry is fragmented and therefore critical mass for offsite construction has not been achieved.

For the benefits of offsite to be more widely understood and applied, the challenge is to create mechanisms that will enable the offsite industry to make its case more effectively by increasing awareness and setting standards.

DTI's initial funding delivered a critical mass of stakeholders in off site and identified and implemented priority actions – a first step in bringing offsite into the mainstream – ultimately achieving a ten-fold increase in the uptake of offsite by:

- Demonstrating the business case,
- Setting standards for the design, manufacture, and construction process
- Resolving interfaces,
- Providing an independent, authoritative source of data, and,
- Providing a forum for discussion of the benefits and challenges to inform and educate construction industry professionals

Organisations committed to Buildoffsite include:
AcerMetric
Acumen7
Anglian Water
Apex Wiring Solutions Ltd
Apollo Adhesives
Armstrong
Arup
BAA
BBA
Department for Business, Enterprise & Regulatory Reform (BERR)
Black Architecture
Bourne Steel
Britspace Modular Buildings Limited
Bryden Wood Associates
Buchan Concrete Solutions
Building on Business Ltd
Caledonian Building Systems
Capita Symonds
CIRIA
The Concrete Centre
Corus
Construction Skills
Costain
Covers Timber Structures Ltd
Crown House Engineering
Danish Technological Institute
Dawkins & Co
Environmental Recycling Technologies for Construction (ERT4C)
Fleming Developments UK Ltd
Framing Solutions
Fusion Building Systems Ltd
Gateway Bathroom Pods
Gazeley
GlaxoSmithKline
Howick Ltd
IBE (International Business Events)
Innovare
Laing O'Rourke
LEaF
Lloyd's Register EMEA
Mike Jackson Associates
Morgan Sindall plc
Mtech
NG Bailey
Ormandy Ltd
Roger Bullivant
Sandwood Design and Build
The Staircase Group
Tarmac
Terrapin Ltd
Tesco
UNITE Group plc
Vision Modular Structures Ltd
Van Elle
Wolseley UK
Yorkon

Associated members of Buildoffsite include:
Building Research Establishment
British Precast
Building Services Research Information Association
CPA
Steel Construction Institutel
Timber Research And Development Association

HSE is not a member or associate member of Buildoffsite but does see the benefits that off site construction methods offer and therefore supports this initiative.

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Loughborough University Research

A research project for HSE by Loughborough University identified site-based case studies that demonstrated commercial cost and safety benefits during the construction process. The study examined the benefits to site workers but did not look at the transfer of site risks to the factory or the risks involving transferring components to site.

Two examples discussed in the report are described below and concerned risks from working at height; muscular skeletal damage from manual handling; and, transporting materials to and around site. Neither example reduced aesthetics, buildability and usability or increased environmental impact.

Case Study 1: Pre-installed windows and glazing within precast concrete cladding panels.

Project – St Margaret's Hospital Regeneration
Main contractor – Carillion
Sub contractors – Trent Concrete (precast concrete units) and Broderick Structures (windows)

Traditional approach

Precast reinforced concrete cladding panels are fixed to site located brackets. The fabrication process involves the manufacture of timber, steel or GRP moulds into which concrete is then cast.

Window frames are made from aluminium or steel and installed as the building work progresses. The frames are then silicone sealed and the windows site glazed. Most common form of window installation is by standing scaffold although mast climbers or scissor lifts are also used. All methods require working at height.

Alternative approach

Carillion identified programme savings and reduced health and safety risks through early meetings with the specialist sub contractors. By installing all windows into the precast units in the factory with factory applied sealants and glazing operations were carried out at ground level and subsequent site erection by crane and cherry picker.

Primary safety benefits from this alternative sequencing were reduced slip and trip hazards for delivery drivers delivering to a factory environment rather than a construction site; reduced congestion at the construction site through fewer lorry visits; reduced muscular skeletal risks through increased mechanical off-loading; reduced glazing and manual handling of glazing units; reduced working at height for window installers, sealant installers and fitters; reduced chance of falling materials; avoidance of scaffolding erection and dismantling; reduced slip and trip risks; reduced working at height inspection time for main contractor and inspecting authorities.

Commercial benefits included reduced costs for scaffolding and cherry pickers; more efficient delivery periods; shorter programme time; less programme risk through factory assembly; better quality of product in the factory; less site damage; cleaner working environment.

Case Study 2 Pre-cast concrete beams

Project - Tesco Supermarket
Main Contractor – Taylor Woodrow

Taylor Woodrow and their design-focused team have developed numerous design methods and processes that reduce site operations though increased factory based fabrication. One method is the installation of precast concrete beams and a "T" section as part of steel column fabrication resulting in reduced programme time for sub-structure work and improved health and safety due to reduced site operations

Traditional approach

The ground or ring beam is the interface between the foundations and the superstructure and traditionally is cast insitu into excavated trenches. The beam is formed on site in its final location requiring intensive use of skilled site operatives constructing steel fabrications, positioning of shuttering and the pouring of ready mixed concrete.

Alternative approach

Prefabricated beams are transported to site where they are then lifted into the correct position. Highly skilled operatives are therefore not required to manufacture shuttering or place reinforcement. The method is less dependant on weather conditions to achieve an accurate result.

Primary safety benefits include very fast installation times reducing site time and labour needs; reduced working in muddy trenches hence reducing slips and trips; reduced manual handling of shuttering, reinforcement and materials; reduced adverse bending requirements for steel fabricators; avoids the use of power tools; avoids concrete burn risk and cement related skin disease as less wet concrete on site; reduced manual handling and slips and trips through reduced material delivery to site.

Commercial benefits include reduced materials waste; faster build programme and better quality.

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Steel Construction Institute - The benefits of offsite construction in urban locations

A study of several construction projects involving various levels of off-site steel construction technology was undertaken by the Steel Construction Institute to identify the benefits of modern methods of construction in urban locations.

The challenges of urban construction

The scarcity of green field sites is forcing developers to build on smaller plots of land within existing residential developments.

Construction on confined urban spaces presents developers with various challenges such as:

- The lack of working and storage space;
- The need to minimise the impact of construction work on local residents;
- The shortage of skilled labour for site construction.

These challenges can be met by the use of off-site construction methods to replace site intensive work activity by, for example, constructing two dimensional panels and three dimensional modules and delivering on a just-in-time basis to suit local conditions without the need to store on site.

Speed of Construction

Off-site construction can be significantly faster than traditional construction. Three schools in Crawley had to be built to a tight timescale to enable them to be opened for the new school term. This reduced the construction programme from 76 to 54 weeks and was only achievable by using prefabricated pre-glazed wall panels permitting a faster weather tight building envelope thereby allowing other trades to work inside the building

Site activity and transport of labour

All sites visited by the researchers as part of the SCI study were noticeably quieter and withy fewer people working on site. The study was able to quantify that the reduction in labour through the use of modular construction methods could be as high as 75% when compared to traditional construction methods.

With less site activity came less noise, dust and general disturbance.

Commercial vehicle movements.

Traffic, including site delivery and waste collection, associated with the construction site is an important source of nuisance with local residents. The delivery of prefabricated components such as panels and modules can be timed to suit local needs avoiding peak times such as the early and late rush hours and the school run. Estimated reduction in commercial vehicle traffic for fully fitted out modules can be as high as 40%.

Waste.

Whatever form of off-site construction is used there can be significant savings in the amount of site generated waste. The study concluded that reductions approaching 70% were possible when compared with traditional techniques. This was due to the virtual elimination of waste board materials and insulation.

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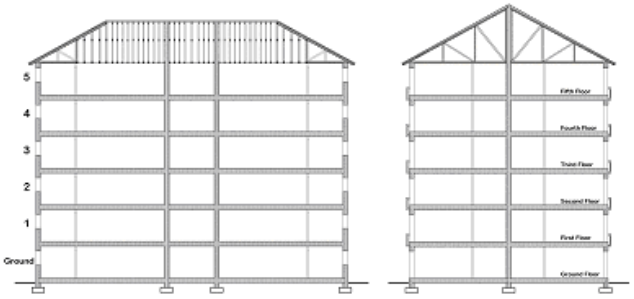
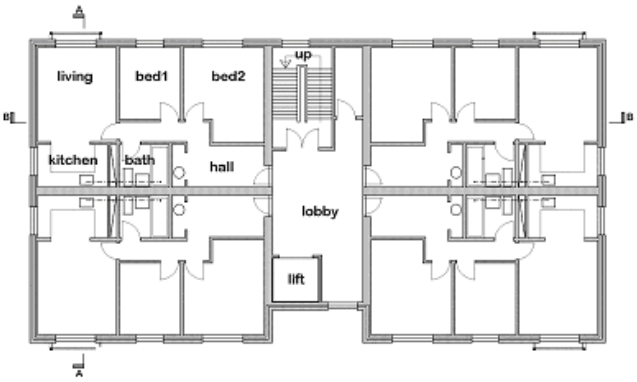
Timber frame construction for high rise buildings

High-rise timber frame building has increased in popularity due in part to a collaborative project between Government, TRADA Technology, TRADA, the Building Research Establishment (BRE) and the timber industry; TF2000 involved the construction of a six storey, timber frame building – the tallest of its type in the world – to demonstrate the commercial and technical benefits of using timber for medium rise buildings in the UK, and to encourage greater adoption of timber frame in construction

The building is within a former airship hanger at BRE Cardington and comprises six floors, each containing four two bedroom flats.

The design was for Housing Association accommodation, suitable for brownfield sites. The timber frame wall panels were constructed with class C16 timber, all UK sourced. An innovative reverse wall was used for part of the structure, the remainder being typical small panel construction, utilising British OSB for sheathing. UK grown timber also features largely in the building's lift shafts, stairwells and stairs while most floor timbers were Swedish C16 timber. All four external elevations were brick clad.





The F2000 project was the extensive tested -,key areas being structural, fire and acoustical performance.

Building Regulations require buildings over four storeys to demonstrate their resistance to collapse when subjected to a specific level of accidental damage - disproportionate collapse compliance. The regulations state, "The building shall be so constructed that, in the event of an accident, the building will not suffer collapse to an extent disproportionate to the cause".

Therefore, a structural designer must consider the removal of a loadbearing support element. It is specified that the area of collapse within the storey and the immediately adjacent storeys must not be greater than 15% of the floor area or 70m^2, whichever is the lesser.

There was no collapse. The ceilings did not fall down. The floor above the internal wall deflected only by 25mm. The externally the brick cladding did not crack and even the resulting timber frame deflection could not be seen.

The structure was tested for the length of its period of resistance to disproportionate collapse. Timber structures are known to be sensitive to time-dependent loading, so the test was extended over a period of 20 hours. A resulting movement of 300mm

over the floor spans of 3.6m is an acceptable limit, but nothing like this occurred during the test.

A fire test programme undertaken in 1999 evaluated the fire resistance of a large multi-storey timber frame building subject to a severe natural fire exposure.

The particular aspects of fire resistance were structural integrity (load bearing capacity) and compartmentation (prevention of fire spread throughout the flat of origin) to provide data to assist in the development of fire engineering design principles for medium rise timber buildings above 5 storeys.

The test fire was ignited in the living area of a second floor flat in the TF2000 building. The test was stopped after 64 minutes at which time neither the compartmentation nor structural integrity of the building had been compromised. The building performed in a real fire equivalent to the Building Regulation requirement of 60 minutes, under furnace fire test conditions.

TF 2000 proved a demonstration to the construction industry of the benefits of timber frame, and showed that perceived drawbacks were false. The tests carried out showed the strength and durability, acoustical and fire performance of timber frame, and also provided an opportunity for engineers to devise improvements to the structure

However, since this work was completed there have been problems.

Colindale Housing fire and others

In July 2007 a construction site in Collindale, London containing two partly built six storey timber frame housing units burnt to the ground. This took less than 10 minutes. The report into this fire in London and other sites in the UK questioned whether this construction method should be used for high-rise buildings.

The report, written by the Fire Protection Association was published the same week that a fire destroyed a multi-storey timber-framed student accommodation block in Newcastle-upon-Tyne.

The FPA report indicated that a cigarette was the most likely cause of the fire in the Colindale timber-frame residential block and asked whether “timber construction should be used for high-rise buildings”

The report also raised the question of whether timber-frame buildings are safe once they are completed but greater consideration to the installation of sprinklers should be given especially building in fire compartments during construction.

HSE’s concerns

As serious as these concerns are over the fire safety of occupants, there are other equally serious problems with this form of construction to add to the debate over safety. These problems concern the stability of scaffolding during the erection sequence of high-rise timber frame structures and the temporary fire protection measures in place to protect and evacuate construction workers in the event of a fire.

The recent fires were structures under construction. Just as on other construction projects precautions are needed such as the appropriate spacing between buildings, proper site programming, and the installation of fire protection early on.

These considerations have been largely addressed by the industry and new protocols have been developed for dealing with potential fire risks during construction and the apparent lack of stability caused to scaffolding systems during the cranage sequence in construction

Appendix 1

Common terms used in offsite construction

Component assembly

This is not true off-site production as it entails the traditional assembly of relatively small building components such as windows, doors, light fittings ironmongery and hardware etc. The components are manufactured off-site but require delivery, storage and skilled assembly as part of the construction programme. In the door example the door, frame, casing, architrave, hardware, glazing and painting are all separate processes.

Non-Volumetric Assembly

Items although preassembled in factory-controlled conditions are non-volumetric and do not enclose usable space. This door-set includes the prehung finished door, frame, lining, casing and glazing assembly complete with all final hardware. The door-set still requires delivering to site, storage while the opening is built and then fitting in place. However, the number of on site trades involved in the fitting of this door-set is drastically reduced as is the time taken to fit it.

Volumetric /Modular Preassembly

These comprise three-dimensional units built in factory conditions that enclose usable space and are then delivered and installed within or onto a building or structure. They are fully finished internally and include toilet, bathroom, washroom and kitchen pods and plug-and-play plant rooms. Benefits of volumetric construction include improved quality, rapid assembly, reduced defects and on-site snagging, less disruption on site, better working conditions, increased predictability and control, and economies of scale. Maximum size of unit is determined by the limitations of transport and site access. The strength and rigidity of construction must be sufficient to allow transportation and craning into position without damage. This strength may require structural members that are redundant in the end-use of the unit and therefore may be regarded as an inefficient use of materials.

Volumetric construction can be in unit form only with the completed unit taken to site and assembled - the finished building completed by many other following trades- or it is the whole building. The examples of Corus Living Solutions and Yorkon illustrate this concept very well.

Most UK volumetric construction has been in sectors providing hotels, student and key-worker accommodation, hospitals, and fast food outlets. Size has been limited to relatively small scale buildings repeated on many sites but there are examples of large, complicated structures with highly sophisticated service requirements now being erected across all sectors.

Appendix 2

Case Study- Van Elle Modular Pre-cast Post-Tensioned Foundations

Van Elle's Smartfoot ® foundation packages provide builders, developers and modular manufacturers a foundations solution available for brownfield and greenfield sites. The system offers all the advantages of modular construction in the ground through speed, quality and accuracy of tolerance. The example shown below at Redrow Housing estate in Malton North Yorkshire uses precast post-tensioned concrete beams installed on prepared concrete piles This is not always necessary. The building is a three-storey semi detached private dwelling on an estate of many similar properties.

The installation of pre-cast foundation beams requires a crane with sound footing and four trained Van Elle site operatives and crane driver. From first lift to finish of post tensioning the time elapsed on the example shown below was 85 minutes for a pair of semi-detached houses. It takes longer to site the crane than it does to lift and place the beams.

Precast concrete piles driven into prepared ground with no excavation required for foundation

Top of pile prepared and typical pile cap cast using lightweight disposable plastic formwork

First lift of pre–cast beam by crane. Four site operatives plus crane driver

Lifting operation almost completed with beams and cross beams placed accurately on pile caps

Lift and post tensioning of concrete beams complete – total build time from first lift to end of tensioning 85 minutes

Potential incidents during lift and placement could have been included crane outrigger hard standing failure, slinging failure, contact with crane, trapping by beams, breakage of post tensioning cables. None of these happened as skilled, trained and experienced operatives expertly managed the whole operation.

Traditional construction methods would have included site clearance; extensive machine-dug excavations; reinforcement and concrete placement - all requiring significant amounts of labour and time and weather dependency.

Unfortunately the savings in time and labour from using off site constructed beams were not seen to be applied to much of the remaining construction of the house build as external walls and roofing were built in traditional ways.

Case Study – Corus Living Solutions Modular Construction

The Corus Living Solutions supplies finished off site constructed 3.8m x 6.3m room modules as part of the procurement of hotels and multi occupancy housing for a variety of clients. The modules shown below are fabricated in the Shotton HQ of Corus for the Ashorne Hill Conference Centre. This project was of high quality with bedrooms and bathrooms arranged either side of a corridor with a staircase module at one end. Service connection to plug and play services were made in vertical riser ducts between pairs of modules.

The modules are 3.8 metres x 6.3 metres external plan dimensions, and this allowed ample space for a bathroom with basin, bath, shower and toilet. The modules are arranged either side of a 1.2 metre wide central corridor with a large staircase module at one end. Service connections were made in a vertical riser between pairs of modules.

The external cladding is made from coated steel panels pre-fabricated in sizes to match the window pattern and supported on vertical rails attached to the modules. The roof is V shaped with internal guttering using down-pipes located in the service zone between pairs of modules. It is clad with composite panels manufactured by Kingspan. The panels were installed rapidly to create a water-tight envelope.

The off-site manufacture of the modules allowed site preparation and module build to be programmed in parallel, reducing the overall project time, delay and expense on site whilst reducing disruption to the client.

The overall construction period took only five months from start on site. The 28 room modules were installed in only three days to create a weather-tight enclosure for later fit-out and finishing. The building was designed to high standards of energy efficiency and comfort and to higher acoustic insulation standards than required by the 2003 Building Regulations.

Production line with modular panel laid flat

Wall panel screwing machine remotely operated

Steel frame and door set being erected

Finished module being stacked ready for delivery to site

Out of a total construction period of 20 weeks from start to handover the placement of 28 room modules only took 3 days to create a weather-tight enclosure for later fit-out and finishing. Off-site work eliminated the need for on-site carpenters, dry liners, plasterers, electricians, plumbers and decorators, insulators.

Fully trained skilled production line operatives with no previous experience of construction techniques carry out work in Corus.

Accidents happen on the Corus production line but are few in number and are mainly tripping and falling incidents as a result of old irregular floors. The laying of a new floor throughout the factory is redressing this.

Case Study 3
Armstrong Integrated Systems Services and Plant

Armstrong Integrated Systems manufacture packaged plant rooms in a bespoke factory environment. Their attitude is that a busy construction site is far from an ideal place to build a complex structure such as a plant room. If you bought a modern car it would be built in a modern super efficient factory – not on the hard shoulder of the M25. The preassembly of the equipment in a bespoke finished shell and then delivered to site for final connection brings major benefits to the worker, the contractor and to the client and end user.

Cost

Independent research by BSRIA shows that off-site manufacture of plant rooms can save as much as 24% compared to the cost of conventional procurement. Factory build removes the 'unknowns' and there is no on cost for site delays, waste and rework.

Efficiency

Off-see manufacture offers faster assembly streamlined planning and confidence in delivery. The system arrives on the day you want it and requires only the minimum of time and resources to complete installation and commissioning.

Speed of Construction

Work can start off site well in advance of the construction programme unaffected by weather and other trades.

Quality

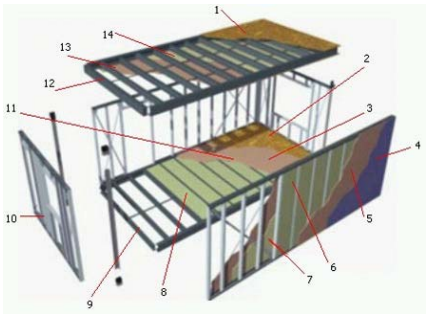
All procedures in the factory follow audit trails under ISO 9001:2000 quality standard and operate under ideal conditions. AIS conduct a 172-point checklist ensuring that each plant room is given a thorough working-order inspection and leaves the factory with zero defects saving considerable time during on site commissioning.

Safety

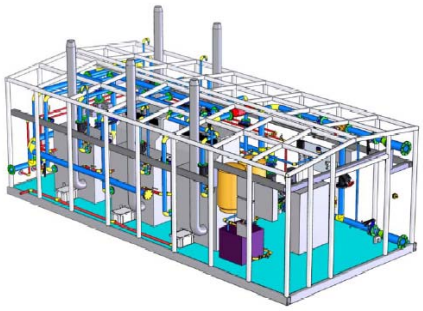
Off site assembly reduces health and safety risks as equipment is assembled on modular base cassettes with open access to all four sides. Overhead lifting equipment is used to move large components. Replicating this level of control on site using traditional assembly methods would be virtually impossible.

Site Access

Delivery to site is a planned operation and greatly eases congestion around the site.



3D CAD drawings and files give accurate visualisation and parts scheduling automatically generating technical drawings used for fabrication. Once delivery date is known fabrication commences. The plant room is delivered on skids and is 'plug and play' with site times reduced to almost zero



Construction of the finished plant room is carried out with 360^0 all round access on a prefabricated floor cassette allowing for good ergonomic working positions. Only on completion of all works including snagging are walls and roof fitted. There are occasions when access is more limited and work off ladders to access higher parts of the plant is required. Finished plant rooms are craned onto a low loader transport buy overhead cranes and delivered to site as either stand-alone units or further craned onto the building.

There are still questions to be addressed regarding safe working practices at Armstrong Integrated Systems and include the use of ladders as work platforms, working in awkward and confined spaces and manual handling of large valves and pipe fittings.

Case Study 4
Corefast

System description

Corefast® is a system developed by Corus using a steel and concrete composite panel system that is manufactured and fabricated off-site into modules up to 3 storeys high. The units can be fitted out with stairs or lift rails in the factory reducing work and number of trades on site. Off-site production allows the lift core of a building to be erected up to six times faster than a traditional reinforced concrete core. The technology also brings many other benefits to the project.

The system of pre-fabricated modules or components is straightforward to assemble and significantly reduces on-site construction time. In addition a Corefast core is a more accurate structure than a concrete core

The Bi-Steel components of concrete and steel are assembled and concrete filled without the need for formwork. The high strength of the core means that its footprint can be reduced to maximise productive space

External or internal walls are prefabricated off-site and delivered ready for immediate erection on simple pre-prepared foundations. Total building costs to include the shell and core using Corefast can be less than for a conventional concrete core

Buildings can be erected in multiples of modules that are up to four storeys high, allowing rapid and safe erection. Two metre wide panels are interlocked using the “slot & lock” system to erect perimeter and internal walls. Panels are prefabricated to receive windows and doors on-site.

Additional internal structural framing and floors can be easily incorporated into the building envelope.

Panels are designed to accept client specific architectural finishes (internal & external).

The Corefast system benefits work on site through strength, speed, quality and protection.

Site safety is enhanced due to fewer hours worked at height facilitating a better build sequence and helps reduce site congestion

The first installation of Corefast was completed in 5 days at the Dundrum town centre development near Dublin. The 24m high lift shafts and stairwells were installed over a 17-day period and comprised four assembled modules. The two lower modules were positioned on foundations and bolt connected to each other. The voids in the Bi-Steel panels were filled with concrete bringing the core to full strength. The upper modules were then craned into position, bolted and completed by concrete infilling of the voids. Total time to erect and assemble modules - 2 days. Total time to concrete fill - 2 days

Case Study
Yorkon
Complete Buildings

Yorkon has pioneered the use of off-site construction for over 20 years and has been credited with changing the perception of modular building in the United Kingdom.

The company offers a 20-year structural warranty and 5 year product warranty as part of its customer care. Other credits to its name include the first modular building company to achieve approval for fire testing in line with the Association of British Insurers and Lloyds; and, the launch of the first software tool to assess whole life costs of modular and traditionally constructed buildings

The biggest building programme in the history of the NHS requires the implementation of new innovations to ensure success especially the development of busy constrained hospital sites.

Work is made much easier by the use of modular offsite construction providing building occupants with a safer, quieter and cleaner construction period particularly critical where new facilities are built adjacent to existing buildings to meet increased capacity and changing functions. Module cranage is timed for weekend and quieter periods.

The Endoscopy Unit shown here has two fully equipped procedure rooms, a treatment room, a two-stage recovery area and a patient and relative waiting area. Modular construction reduced the time to erect the building on site from two months to four days. Noise levels were minimised and there was no disruption to patient services

Yorkon constructed the UK's first PFI project to be built off-site. Ladies Walk Centre for Dudley Priority Health NHS Trust provides a one-stop shop for a wide range of patient services. A two-story building designed around a central street incorporating a striking glazed entrance and glazed roof to maximise natural daylight.

Yorkon also construct in other sectors. Built on a brownfield site, the £2m Sixth Avenue Apartments project provides 24 homes for rent in York. Occupying a prominent corner location in a residential area, the four-storey development provides a mix of quality 3, 2 and 1-bedroom accommodation, including one apartment for a supported living scheme for people with disabilities. The apartments have reduced provision for car parking to help reduce dependency on cars and encourage sustainability.

Forty-eight steel-framed modules were manufactured at Yorkon's production facility in York, while the foundations were progressed on site. The apartments were fully fitted out off-site with all plumbing, electrics, doors, windows, bathrooms, kitchens, and tiling pre-installed. They were delivered to site and installed in less than a week.

Case Study
BUMA
Barling Court, Larkhall Lane, Stockwell, London
Complete Building

Barling Court is a scheme for affordable housing for key workers in London comprising high-quality low-cost housing in Stockwell, London where a four-storey block of eight flats was built in four days. The building was fully finished with all the services working and the site cleared and landscaped in less than four months.

This very short build programme was achieved by using the BUMA system of volumetric construction where the eight flats for Hyde Housing Association were manufactured and assembled in the BUMA factory in Krakow, Poland, and brought by lorries to the site The modules were craned onto prepared concrete strip foundations and bolted together with galvanised-steel fixing plates. The communal entrance and staircases leading to all the flats were manufactured as four modules – one for each floor.

Despite the distances involved in transporting the volumetric units all the way from Poland – and with skilled Polish workers to erect them – the total construction cost including all fitting-out was £700,000 in September 2004, which is an average of £87,500 per apartment, excluding the cost of the land.

Hyde Housing Association says the BUMA system of volumetric construction is at least 12 per cent cheaper than traditional new build, and anything from 20 to 30 per cent less than equivalent modular systems. Given that the apartments were built in a quarter of the time taken by traditional construction, and that they can be unbolted, transported to another site and re-erected, this appears to offer a way of dealing with the present housing shortage while allowing the prospect of re-using the homes elsewhere later if things get better.

These flats have high-quality fittings, smooth plaster finishes, solid floors, and good standards of sound insulation and energy efficiency. The façades are neatly detailed, with aluminium cladding panels, external balconies and sliding sunscreens of slatted timber.

The construction has a life of 60 years and its versatility is shown by the prototype made by BUMA in 2000 being demounted and re-erected eight times before becoming a permanent family home outside Krakow.

Case Study
Wilson James
Construction Logistics

A construction materials consolidation centre in south-east London has improved site efficiency and dramatically reduced vehicle movements.

The warehouse, known as the London Construction Consolidation Centre, is a distribution centre for five central London construction sites. Materials for the schemes are delivered to the Centre - which is well located for arterial roads leading into the capital - sorted and all the goods needed for a few days' work collated and delivered by one lorry rather than several.

This approach to construction logistics cuts congestion and pollution and also site waste as there are fewer materials on site waiting around to get damaged.

Over a twelve month period Constructing Excellence has monitored the process and reports as follows:

- The initial target was to reduce vehicle movements into central London by 40%. The centre, operated by logistics specialist Wilson James, has achieved a 67% cut.
- The centre delivered 97% of materials to the right place at the right time in good condition, compared with an industry average of just 30%
- 70% or more reduction in carbon emissions caused by fewer vehicle movements and use of an efficient delivery fleet
- 47% improvement in materials-related site productivity, because workers didn't waste time looking for materials
- 25% improvement in site safety thanks to a reduction in the double handling of goods and a corresponding reduction in the risk of slips, trips and falls
- The number of tickets issued for speeding, parking and other traffic offences significantly reduced
- Other benefits include serious cuts in damaged materials and packaging waste, and,
- a 100% guarantee that materials will be on site within 24 hours and increased inventory control for subcontractors.

Is this format suitable for consolidation centres in every London Borough and on the edge of other major UK cities? The problem is one of money as the Centre was a two-year pilot project that relies on a subsidy of £1.85m from Transport for London (TfL).

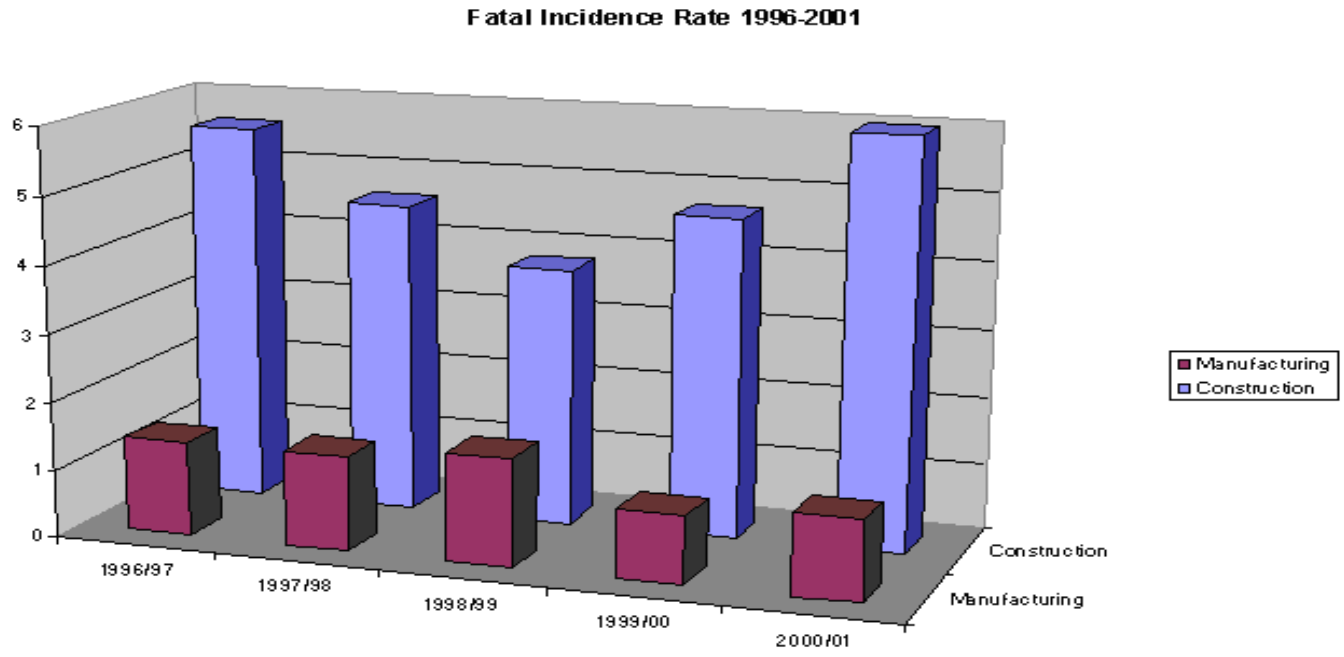
The remaining £1.35m of its £3.2m funding came from developer Stanhope, Wilson James and contractor Bovis Lend Lease, which used the centre for deliveries to five projects they are working on together. This is not enough to make it self financing as it needs around six ongoing projects to be sustainable.

The challenge is that sites need to organise themselves to benefit from the concept – a process including organising sites to benefit from reliable just-in-time deliveries and getting out of the habit of over-ordering materials to compensate for damage and loss. Both developers and TfL are convinced that consolidation centres are the right way to improve site efficiency and reduce congestion.

Appendix 3 Site Specifics

The Health and Safety Implications from Off Site Production

Is Off-site production (OSP) safer and less hazardous to construction personnel than traditional construction methods? HSE statistics indicate that fatal accidents in construction are five times more likely than in the manufacturing sector.



The actual situation is not clear-cut as the 'manufacturing' sector includes all manufactured goods and 'manufacturing for construction' data is not available. Hazards inherent in traditional construction activities change when the processes are moved to the factory environment. In many cases the hazards on site are completely removed or are easier to reduce and control in a factory.

A recent research project at Loughborough called the ConCA project examined accident causality in traditional construction. The research showed that many accidents occur off-task where operatives are moving around site not directly associated with their main tasks. Off Site Production significantly reduces the number of site based personnel and hence can seriously reduce the number of off-task accidents.

The large-scale mechanical activities of building mean that health and safety issues may sometimes be overlooked. The following photographs and OSP benefits are those identified across several projects involving components and elements manufactured off-site.

Off-Site Construction in the UK Building Industry- A Brief Overview

Below are a number site specific structures that used off-site manufactured or pre-cast components. Each lists some of the main health and safety benefits and disbenefits of these OSP approaches. Text, layout and photographs are courtesy of Loughborough University.

In-situ augered piles

A traditional system of piling that has the following major risks;

- breaking out concrete,
- dermatitis,
- dust inhalation
- HAVS
- MSDs
- proximity to heavy plant
- exposure to UV
- noise
- working below ground level increasing water-borne diseases (e.g. Weil's disease)
- slips, trips falls
- earth collapse

The use of OSP concrete piles and pile caps have several benefits that include;

- elimination of contact with contaminated spoil,
- no concrete hazards,
- reduction in manual handling,

Eliminate the need to break out the pile to reduced level with associated benefits such as;

- elimination of power tool risks,
- HAVS
- Noise
- RSI
- Dust
- control of work area,
- reduction of trades and personnel onsite,

The use of OSP concrete piles and pile caps have several benefits that include;

- To break down pile cap use automatic techniques (e.g. Taets Hydraulic Pile Breaker www.taets.nl)
- The placement of the pre-cast capping beams can facilitate the use of lifting points which can be clearly marked, to ensure safe lifts

Bridges and Roads

A bridge abutment using the pre-cast panel re-inforced earth system. This system utilises OSP PC concrete panels together with stainless steel reinforcement strips embedded in well graded backfill, this obviates the need for insitu concrete and its associated risks, such as

- Dermatitis
- HAVS
- MSDs
- manual handling of large diameter re-inforcement bars,
- construction of falsework and formwork and associated risks,
- cuts
- MSDs
- HAVS
- Multiple trades

A hybrid bridge which has PC concrete decking panels used in conjunction with rolled steel beam sections. This system obviates the need for bridge deck falsework and formwork, and the associated risks of;

- working at height,
- MSDs,
- manual handling,
- multiple trades
- HAVS
- manual handling of large diameter re-inforcement bars,
- placing and compaction of insitu concrete,
- dermatitis
- HAVS
- MSD's

Culverts and Tunnel shafts

The use of OSP PC concrete culverts eliminates the need for;

- construction of falsework and formwork and associated risks,
- cuts
- MSDs
- HAVS
- manual handling
- manual handling of large diameter re-inforcement placing and compaction of insitu concrete and associated risks of dermatitis, HAV's and MSD's

Shaft lined with OSP PC concrete segments eliminates prolonged working within confined and enclosed environment. The risks with this are;

- working in compressed air,
- explosion
- tunnel collapse
- toxic gases
- water ingress
- any form of manual handling

Concrete Structures

Concrete panels made in the factory for walls and structures in the factory allows more control of;

In situ concrete and its associated risks, e.g.

- dermatitis
- HAVS
- MSDs

construction of falsework and formwork and associated risks,

- cuts
- MSDs
- HAVS
- manual handling,

working environment including,

- air quality (dust)
- UV exposure
- noise levels

work station, for example ,

- delineation of factory into separate storage and working

zones

job rotation, to minimise repetitive tasks that cause,

- HAVS and MSD's
- RSI
- Working in confined spaces

Steel Frame

Pre-assembled steel frames reduces the risks of;

- HAVS
- Cuts
- MSDs
- Manual handling on site

Cladding

The manufacture of cladding panels within a factory environment changes or allows better control of the main risks, some of these are listed below;

- working environment including,
- air quality (dust)
- UV exposure
- noise levels
- hazardous material risks,
- concrete dermatitis
- dust, grit or brick splinters
- work station,
- delineation of factory into separate storage and work areas

Finishing a panel within a factory environment allows better control of the operative's tasks, for example,

- job rotation, to minimise repetitive tasks that cause,
- HAVS
- RSI
- MSDs
- working in confined spaces
- working at height,
- control over trade overlap

Light Cladding

The benefits of OSP unit installations are;

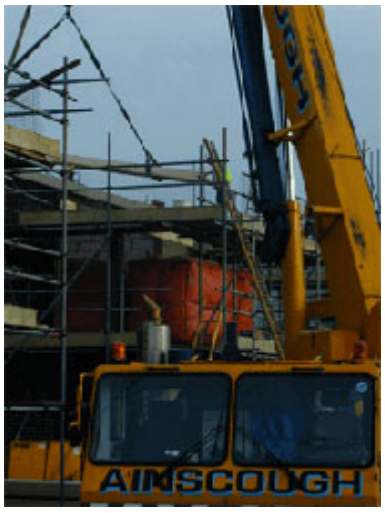
- better control over mobile plant risks,
- falling material
- overturning crane
- contact
- minimal manual handling and associated risks,
- MSDs
- RSI
- allows installation at a safe distance from an unguarded edge,

- More organised as fewer, larger deliveries
- More likely to be mechanically handled
- Transport and delivery method minimise manual handling
- Weight and centre of gravity and safe lifting points can be clearly identified on each element to facilitate mechanical and manual handling where appropriate.
- Packaging and orientation can be arranged to facilitate safe unloading without double handling

Best practice installation use tele-operated vacuum lifters.
This technique reduces the likelihood of accidents resulting from falling objects dropped by site installers as the panels have been assembled using OSP and are not reliant on site assembly. This avoids the need for working at height when installing the panels as all the work is carried out internally, from behind the edge protection handrail and not the off the scaffold. Installation method allows edge protection to remain in position during panel installation and that operatives do not need to work outside of barrier

Roofing

Composite panel roofing



The following illustrate aspects of the installation of pre-assembled roof panels.

- Overall control and cleanliness better within the factory environment, providing
  - less risk of contamination,
  - better control of gluing operations,
  - less risk of trips, slips, falls,
- Materials are mechanically handled right to the workface,
- Work in open spaces as against the confined spaces on-site,
- Significantly lower trade overlap and interface,
- Work at workbench level, with reduction in MSDs, as no crouching required,
- Almost entire elimination of working at heights,
- General welfare facilities better in the factory environment

The risks of undertaking these operations traditionally include;

- working at height for longer periods,
- falls through exposed roofs,
- falling materials,
- exposure to UV,
- slips, trips and falls,
- MSDs from manual handling of materials at height and in awkward positions,

Internals

Bathroom Pods

The installation of large office washroom pods in the factory allows more control of insitu concrete and its associated risks, such as

- dermatitis
- HAVS
- MSDs
- construction of falsework and formwork and associated risks,
- cuts
- MSDs
- HAVS
- manual handling,
- working environment including,
- air quality (dust)
- UV exposure
- noise levels
- work station, for example delineation of factory into separate storage and working zones
- job rotation, to minimise repetitive tasks that cause,
- HAVS
- RSI
- MSDs
- working in confined spaces

Installation of pods obviates the need for large onsite installation teams, The installation, being a large event of short duration, allows management to focus more fully on H&S issues,

However increased risks of pod installation include increased consequential risk of injury that can occur with large loads

Mechanical and Electrical Services

Mechanical and electrical services provide good examples of the health & safety benefits that can be derived from OSP. The following photographs and benefits are those identified across several projects involving components and elements manufactured off-site.

Below are a number of photographs (courtesy of Crown House Engineering) demonstrating different stages of the manufacture of different mechanical services components? The first two photograph show stages of horizontal riser manufacture, typically used within new airport buildings. The last three photographs depict some stages in the manufacture and installation of horizontal distribution modules, typically used in airports, hotels, office blocks, shopping centres etc.

Each photograph lists some of the main health and safety benefits and disbenefits of these OSP approaches.

Service Risers

The photograph alongside shows the typical assembly-line approach to riser and plant-room production in a factory. The H&S benefits over traditional include:

- Overall control and cleanliness better within the factory environment, providing
  - less risk of contamination,
  - better control of welding operations,
  - less risk of trips, slips, falls,
  - less risk of HAVS, MSDs,
- Materials are mechanically handled right to the workface,
- Work in open spaces as against the confined spaces on-site,
- Significantly lower trade overlap and interface,
- Access to all parts of the module, by ladder or other means, not possible on-site,
- General welfare facilities better in the factory environment

Alongside is a photograph of an installed riser module. The H&S benefits over a traditionally built approach include:

- Significantly lower number of on-site workers will reduce risk,
  - virtual elimination of MSDs and cuts,
  - virtual elimination of slips, trips and falls,
- Heavy complex installation, but with much fewer on-site operations,
- Less on-site commissioning needed, and therefore lower risks of electrocution, etc.

On-site works almost totally mechanical and therefore involve little manual handling. New risk introduced where this heavy load may need to be pulled or pushed into place,

Horizontal Distribution Modules

The following three photographs illustrate aspects of multi-service distribution modules. The H&S issues of OSP are:

- Overall control and cleanliness better within the factory environment, providing
  - less risk of contamination,
  - better control of welding operations,
  - less risk of trips, slips, falls,
- Materials are mechanically handled right to the workface,
- Work in open spaces as against the confined spaces on-site,
- Significantly lower trade overlap and interface,
- Work at workbench level, with reduction in MSDs, as no crouching required,
- Almost entire elimination of working at heights,
- General welfare facilities better in the factory environment

Quality control, inspection and commissioning of modules off-site provides H&S benefits such as:

- Better control of 'power-on' for electrical components and chill beams,
- Safer workbench level inspection possible, with no work at heights,

Reduces people on-site,

pre-installation unit with the final ceiling finishes pre-fitted in the factory. H&S benefits include:

- Significantly lower number of on-site workers will reduce risk,
- virtual elimination of MSDs and cuts
- virtual elimination of slips, trips and falls
- Heavy complex installation, but with much fewer on-site operations,
- Less on-site commissioning needed, and therefore lower risks of electrocution, etc.
- On-site works almost totally mechanical (using scissor-lifts) with little manual handling. New risk introduced where this heavy load may need to be pulled or pushed into place,

Work at height still needed to connect and fix modules in place.