ace Project Speed Briefing

Project Speed & off-site manufacturing

February 2022

ace

As Government plots our economic recovery from the pandemic, it has emphasised the importance of investing in our built environment.

In June 2020, the Prime Minister highlighted the need to deliver new infrastructure and buildings quicker, under the banner of Project Speed.

At the same time, he spoke of "building back better" and the subsequent National Infrastructure Strategy emphasised that through Project Speed, "vital infrastructure like schools, hospitals, transport and other networks will be delivered better, greener and faster"[1]. A significant element of this agenda is aimed at increasing the rate at which houses are built, which includes the target of 300,000 homes per year[2].

The COVID-19 pandemic has already produced examples of project delivery being accelerated, notably the Nightingale hospitals. Similar approaches will be required if we are to fully reshape how we deliver future infrastructure programmes.

The Association for Consultancy and Engineering (ACE) has produced this briefing note as part of a series on Project Speed, with others exploring homes, hospitals, schools and rail.

Find out more at www.acenet.co.uk/project-speed.

Background

Off-site manufacture has a long history in the UK. Post World War II saw wide-spread use of the technology – with over 425,000 homes being built in 1968 alone.

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Benefits

Off-site manufacture allows superior performance compared to traditional methods, without compromising cost, quality or time.

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Risks

Concerns over take-up, Government policy, global competition, intellectual property ownership and whether modular construction will be accepted by the public are among some of the key risks.

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Realising the benefits

The construction industry has already moved towards more use of digital, but what else will support broader application?

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Specific ACE membership recommendations

Making progress on consistent demand, facilitating the efficient use of offsite and adopting standardised pre-manufactured component and module-based approaches.

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EXECUTIVE SUMMARY

Upgrading our infrastructure is vital, but given the current situation we are in, with pressure on the public finances combined with political ambitions around Net Zero and 'levelling up', this investment is only viable if it can be delivered in a better way. As the Prime Minister said in his June 2020 speech announcing Project Speed, "We will build better and build greener but we will also build faster" emphasising the aim is both about speed of delivery, and ensuring we have a built environment that is fit for purpose.

The visions of Project Speed and Building Back Better are achievable, but we are not there yet. ACE analysis of the top 100 projects identified in the 2020/21 National Infrastructure & Construction Pipeline estimated that six months after the Pipeline's publication 14% were slightly delayed and 7% were significantly delayed[3]. Only if we transform the way our built environment is designed and delivered can we address these endemic challenges, and part of that is making off-site manufacturing a natural part of many built environment projects.

Off-site manufacture has a long history in the UK but – to date – has never become 'mainstream'. Yet the evidence shows that it can be a key method for addressing several key issues facing the UK, including the housing crisis and achieving carbon Net Zero. Off-site manufacture can improve construction productivity, can improve the quality of buildings and infrastructure, decrease the time it takes to construct a building and decrease the cost of building. Off-site manufacture can do all this while being more sustainable – with reduced pollution from transport around the site as well as improved health and safety.

The experience of ACE members, backed up by research from the National Audit Office (NAO), McKinsey and others shows that the use of off-site manufacture at scale can routinely reduce the cost and time of construction by 30-50%. Applied to £11.7bn planned social infrastructure spending 2022/3 to 24/5, this would equate to a 'benefit' of £3.5bn-£5.9bn[4].

Despite these advantages, decisive action is needed to make offsite manufacture an everyday reality. There are encouraging signs – the government has talked of talked of a "presumption in favour of off-site"[5], and its publication *Transforming Infrastructure Procurement: Roadmap to 2030*[6] commits the government to "enabling an increasing the use of 'platform' approaches in construction" but we now need the sector as a whole to make this a reality. More recently, the Government published its review commissioned by Lord Agnew and led by Professor Mosey with a brief to create a new 'Gold Standard' for public sector frameworks and framework controls. Within it contained a series of proposals aimed at Modern Methods of Construction (MMC) and promoting off-site manufacturing."

Figure 1: Timeline for success

The vision of much wider use of platform approaches and off-site manufacturing set out in *Transforming Infrastructure Procurement: Roadmap to 2030* is welcome and the key elements make sense. The priority now must be for this vision to be turned into a detailed strategy that both public sector and the industry can work to.

The Government should:

- Deliver the commitment in *Transforming Public Procurement* to implement 'within two years' a mandate to require 'repeatable social infrastructure' to be delivered using a platform/offsite approach.
- Ensure wide compliance with the Construction Playbook – which through its encouragement of the use of value-based procurement and the CIH value toolkit will facilitate consideration of offsite manufacture opportunities.
- Include more specific detail in the National Infrastructure and Procurement Pipeline on projects which plan to use off-site (this will help aggregate demand for off-site – the current self reported definition of 'using some form of MMC' is too general to do this).
- Fund off-site training and qualifications for off-site construction skills.

The construction and infrastructure sector should:

- Advocate the benefits of off-site manufacturing to all stakeholders – ensure that off-site construction does not have the unfair stigma of "restraining design".
- Embrace more collaborative delivery models with early engagement between client, designer and off-site manufacturing contractor to explore off-site opportunities.
- Adopt the more standardised platform approach to pre-manufactured components.

Transforming Public Procurement proposals to encourage off site manufacture

- Harmonise technical standards.
- Aggregate demand.
- Develop configurators.
- Adapt quality processes.
- Explore risk and delivery models.
- Mandate platform approaches for social infrastructure with repeatable design.

Source: Transforming Public Procurement: Roadmap to 2030 (HM Treasury, September 2021)

BACKGROUND

Off-site manufacture has a long history in the UK. The post-war World War II period and the 1960s saw wide-spread use of the technology – with over 425,000 homes being built in 1968 alone. Much of this building work was manufactured offsite. The technology allows rapid construction of buildings and homes; even with an acute shortage of skilled construction workers.

Off-site manufacture involves the process of planning, designing, fabricating, transporting and assembling building elements for rapid site assembly to a greater degree of finish than in traditional piecemeal on-site construction[7]. Off-site manufacture has been positioned as a key construction technology, and the government has now adopted a presumption in favour of it. However, it has not been adopted to the extent to which we are able to say that it has become the norm in the UK.

Modular and off-site

It is important to understand the distinction between modular construction and offsite, however this is a rapidly shifting environment, and we suggest it's better to consistently refer to modular as a form of offsite rather than an alternative or more advanced format. There is a spectrum of off-site manufacture, from having just basic materials prepared off-site to having entire buildings constructed off-site. Off-site manufacture should be understood as an umbrella term for a range of technologies, while modular construction is more specific. Volumetric modular construction sees large three-dimensional components constructed off-site, and these repeated sections, called "modules", are then installed on-site[8]. A recent notable example of modular construction in the UK are the pair of residential towers in Croydon, which when completed will be the world's tallest modular buildings[9].

The Lord's report, *Off-site manufacture for construction* defined off-site manufacture in order to allow discussion to share a common definition[10]. We shall use the terminology developed in that report for consistency and to encourage others to do so.

Off-site manufacture as defined in this report is any of the following methods:

- Components of the building manufactured off-site and then brought together onsite, such as columns, floor slabs and beams. This includes precast concrete.
- Two-dimensional panelised construction, where structures are designed and manufactured in wall and ceiling panels off-site then joined together onsite.
- Elements of buildings sub-assembled off-site. This is where essentials, such as plant-rooms or bathroom pods, are manufactured in a factory.
- Buildings manufactured volumetrically, or in modules, where whole segments of the buildings are manufactured three-dimensionally and assembled off-site then the completed modules are fitted together onsite.

Why is off-site manufacturing needed?

Off-site manufacture has many benefits, which are developed in more depth later in this paper. This paper also looks at some of the risks of the approach and develops some recommendations for how government can enable this benefit. Broadly, these benefits are increased productivity both in the construction industry and more widely, better quality, decreased project timescales, cheaper projects, improved sustainability, better health and safety and reducing the operational downtime associated with building work.

Off-site has long been thought of as a solution to many of the problems facing the construction industry in the UK. McKinsey & Company highlighted widespread labour shortages and unmet demand for housing as two of the biggest challenges facing construction and recommended off-site manufacture as a potential solution. The *Farmer Review* of the UK construction labour model summarised the construction industry as suffering from the following symptoms: low productivity, predictability, fragmentation, adversarial pricing models, poor training, workforce size, lack of collaboration and innovation. The report recommends an investment charge of 0.5% for off-site manufacturing investment, amongst other things, and a government initiation stimulus in pre-manufactured solutions[11]. The report also recommends an ecosystem approach "to improve relationships and increase levels of investment in R&D and innovation in construction by changing

commissioning trends from traditional to pre-manufactured approaches". The construction sector remains the least productive industry in the UK economy, at more than 20 percentage points below the average output per hour for the whole economy in 2017. The construction productivity index, as baselined from 1994, is well below manufacturing and services, and the whole economy[12]. Off-site manufacture represents one of the solutions to the problems plaguing the construction industry.

Beyond the construction industry, off-site manufacture is a vital technology that can help tackle some of the biggest challenges that face the UK today. The housing crisis, poor quality housing and country-wide infrastructure, are all key challenges that can be more effectively addressed through off-site manufacture. Off-site manufacture also allows for the UK to develop capability and become a leader in robotic automation technologies.

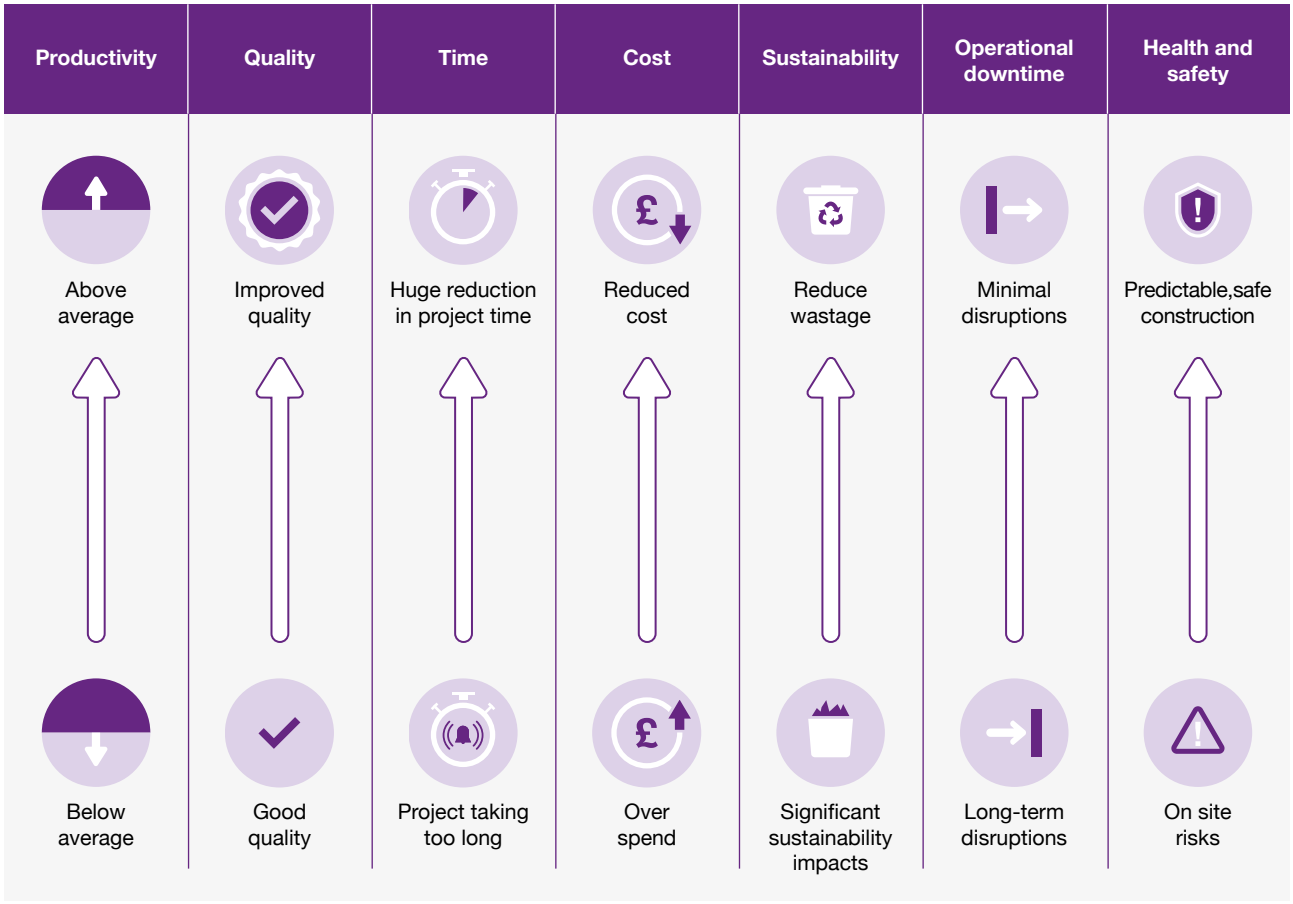


Figure 2: Benefits of off-site manufacturing

Recent developments

It is important to understand off-site in the context of current construction in the UK.

One instance is where it is part of a vertical supply chain model, where more control over delivery is required. Companies such as student accommodation and buy to rent developers and operators have adopted this approach, developing volumetric modular building systems suited to their limited range of building configurations, manufacturing the system themselves and supplying to suit the programme requirements of their construction projects. They gain the benefit of predictability, speed of construction and the control that this methodology brings, and they have sufficient standardisation and pipeline certainty to enable it to be used efficiently.

Some contractors have also led the use of off-site manufacturing for construction, particularly one ACE member, which invested in the development of several off-site pre-cast concrete components that can be incorporated into hybrid structures to increase the flexibility of use.

These examples start to show where off-site methodology has been easiest to introduce, despite the significant up-front investment that each represents. The factors that have enabled it to happen can be summarised as follows:

- Predictability and steadiness of demand for the manufactured system or components.
- Enough standardisation to ensure the efficient use of a manufactured approach.
- Control of the product requirements – e.g. owner-operators, vertical integration models.
- Flexibility and adaptability of the manufactured product. The more component or platform-based the approach is, the more it can be used across a wider range of projects.

Internationally, the lean to off-site is much more developed. According to Forbes, during the 2017-18 period, only 7.5% of the homes built in the UK used prefabricated or modular elements compared to 15% in Japan, 20% in Germany and an immense 84% in Sweden.

In 2019, five government departments committed to a presumption in favour of off-site construction. The Department for Education (DfE) is leading the way and procured 22 contracts through dedicated off-site frameworks. In January 2020, the DfE announced the contractors it would use for its new £3bn framework, to build 30 schools per year using off-site manufacture over the next four years[13].

However, other public bodies are lagging, with the remaining four departments procuring just one contract off-site component between them. There is a need for the Government to move from having a presumption in favour of off-site construction to helping make off-site construction a reality.

Where we should be using offsite

Affordable housing

National Housing Federation (NHF) estimate that housing need is 340,000 homes per year, 145,000 of which must be affordable[14]. London needs 66,000 homes per annum over the next 25 years to meet needs – 65% of which need to be affordable[15]. The Offsite Construction Market Report – UK 2021-2025 shows the market for offsite housing is estimated to have increased by 6% at manufacturers sales prices in 2020'.

Some modular dwellings can be 95% built off-site and are fit for mortgages. Modular houses can also be fully demountable – able to provide temporary meanwhile use or permanent housing solutions. Modular constructed dwellings also have fire-hazard benefits. Separation between modules and enhanced quality control due to manufacture in a factory-controlled environment provides an enhanced barrier to spread of fire, which might aid in avoiding another Grenfell Tower disaster.

Until recently, there has been limited government incentives and a lack of support may hold back the opportunity to grow and expand this area of the market. Over the short term, key to increasing the roll-out of offsite housing is Homes England's Strategic Plan 2018-19 to 2022-23. The plan includes a budget of £27bn, with key programmes including the £4.5bn Home Building Fund.

Built to rent homes

Off-site manufacturing housing is particularly suitable for rented accommodation where it is possible to develop standard apartment types. Reduced construction time means homes are occupied sooner, and rents begin to materialise quicker contributing to enhanced investment returns[16].

Elderly care

Similarly, off-site manufacture suits this rapidly expanding segment of the market where again standard accommodation types can be developed which are then constructed to high thermal, acoustic and quality standards.

Education

The Department for Education has led the way for procuring off-site manufactured projects, recognising the benefits. In 2020, the Department announced the winners of a £3bn off-site framework. This framework will deliver 30 schools a year over the next four years as part of the department's latest school building programme.

Custodial
Prisons lend themselves to standardisation, particularly the cells. HMP Berwyn had wings made from pre-cast concrete, which were pieced together, with the mechanical and electrical services being craned in as complete units fitted to risers. A police hub and custodial suite in Exeter was built using precast concrete for the cell units.

Defence housing
Defence housing is another area which is suited to off-site and particularly modular housing. There is a big need to replace poor quality and poorly performing single living accommodation, much of which in the future will need to be capable of redeployment, which suits the capabilities and benefits of modular construction.

Roads
The vast majority of highway infrastructure is already manufactured offsite or modularised such as pre-cast bridge beams, inspection chambers, etc.

Hospitals
In China, off-site manufacture has been used to great effect in building hospitals. Hospitals built to handle the 2003 SARS and coronavirus pandemics were constructed with incredible speed. A hospital in Wuhan, the area initially worst affected by the pandemic, was constructed using off-site manufacturing in just 10 days. In the USA, an ACE member uses pre-assembled wall systems including all complicated bed head services together with modular plant rooms to improve quality and rapidly increase the speed of construction of these complex buildings.

BENEFITS

A traditional model for outcomes in construction is the cost, time, quality triangle. The model suggests that selection of any two options is possible but comes with a compromise of the third, i.e. it is possible to have a high quality building, a quick project but that to achieve this cost will be compromised. Off-site manufacture provides the potential to change this dynamic. Off-site manufacture allows superior performance across cost, time and quality, as compared with traditional methods, without compromising cost, quality or time.

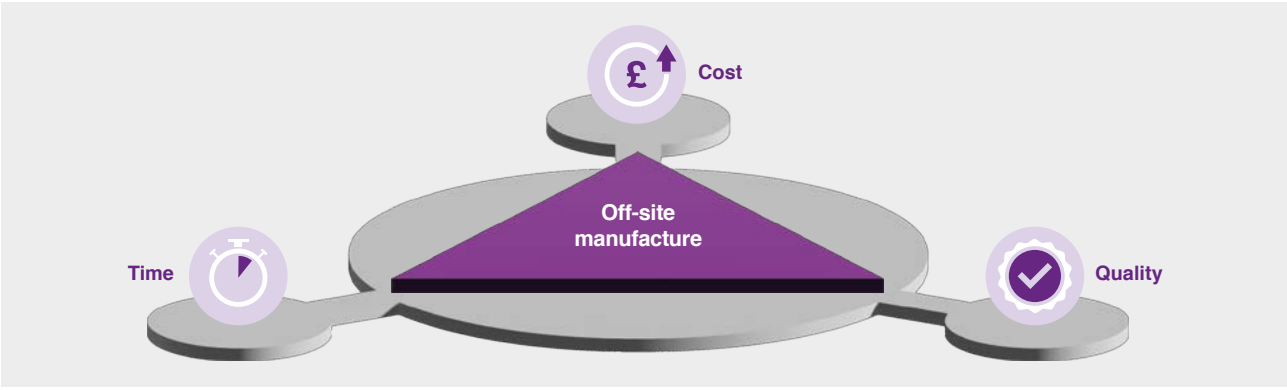


Figure 3: The traditional Cost-quality-time project model is not applicable to application of Offsite Manufacture, where all three elements can be uplifted.

Productivity

Productivity is one of the key issues with the UK construction industry as highlighted by the Farmer report. Off-site manufacture offers a number of a ways to improve productivity.

ACE have found that far less labour is required to construct a building in a factory setting. The Steel Construction Institute (SCI) has claimed that hands required could be reduced by as much as 75% on a four-storey residential development, savings that are similarly large in other kinds of build. Less workers of course means less wage costs for the company. Off-site also offers the opportunity for 24-hour, shift working, whereas on-site construction is time constrained.

While training to be an expert in onsite construction is a lengthy process, teaching workers to perform their role is an offsite build is much simpler and faster. Transferring the construction process to a factory setting essentially turns building into a manufacturing process, and each worker need only learn their own small role in the production line. Less training means faster delivery and money saved. The work environment that it is possible to offer is also significantly different to a traditional construction site thereby potentially making it more attractive to a wider more diverse workforce.

Off-site manufactured Liverpool Street Crossrail platform had 50 fewer workers than the comparable Tottenham Court road installation; 12 less snags and 79,788 less man hours. Platforms were constructed four times faster than in situ.

Precast platform solution at Liverpool Street	Traditional methods at Tottenham Court road	Improvement
30-week construction period	41-week construction period	11-week saving
7 strong installation team	57-strong installation team	50 less operatives
61 hours worked per week	96 hours worked per week	35-hour reduction per week
617mm of platform installed per hour	152mm of platform installed per hour	465mm increase per hour
2,492 man-hours in total	82,080 man-hours in total	79,558 less man-hours

Table 1: Liverpool Street Crossrail

An ACE member found a 6% productivity increase at Manchester Airport car park compared to traditional– with 90% of the build using DfMA.

Another ACE member is able to produce 250 housing modules per annum from a production line employing just 47 skilled and semi-skilled operatives, material movers and supervisors – dramatically reducing the requirement for skilled tradesmen on site plus the cost of providing welfare and other facilities to support them.

Quality

For modular housing, ACE members have recognised the following benefits: higher sound insulation between units: +5dB higher than the ADE building regulation acoustic separation requirements between units. Precision manufacturing and construction minimises heat loss, reduces energy demand and maximises benefits of heat recovery and air quality. One-hour plus fire resistance achieved in floors and walls between modular units. Improved fire stopping due to the use of precision components in lieu of site applied sealants. In addition, thermal bridging within the building fabric can be achieved by a fabric first approach backed by clever detailing and precise tolerances which reduces heat loss and prevents condensation and mould growth. They have found space heating costs are 90% less than traditional and local pollution and disruption is minimised due to the huge reduction in the number of vehicle movements and reduced site activity.

More generally, modular buildings have been shown to provide a better life cycle performance, for example a building's energy performance, among others[17].

Time

The reduced time to construct is one of the primary benefits on off-site construction, and so is a focus of this paper. Project length predictability was cited as one of the key issues that the Farmer Review found with the UK construction market. Predictability is much increased using off-site methods – and has been described as the biggest benefit of off-site manufacturing.

Time savings are inherent to off-site manufacturing and it is one the biggest drivers for the increasing uptake in utilising these techniques on major UK construction projects. Cost of construction is proportional to the programme which is the length of time constructing on site and as such due to the cost of labour deployed, site set up and project finance interest costs. Delays to site works are therefore proportional to increase of costs.

An ACE member delivered a six month programme saving for Heathrow's Terminal 5 using a Design for Manufacture and Assembly (DfMA) solution for a critical roof element. That member also ensured on-time delivery at Heathrow T2A, despite a continuously evolving scheme.

ACE research has found that by building offsite, the process is the same every time, meaning that each time the process is performed, the time taken can decrease. Work can be guaranteed to be delivered on time and to the highest quality, as the mitigating circumstances such as bad weather do not delay the project.

In traditional reinforced concrete projects, the structure is constructed "in-situ" on site. This often involves the following common site operations:

- Tying large numbers of loose steel reinforcing bars into cages.
- Constructing timber formwork to contain the wet concrete as it cures.
- Pouring wet concrete and leaving to cure for a period of time before removing formwork and its full strength is achieved, ensuring large volumes of wet concrete mix is perfectly compacted to achieve adequate strength.
- A precise programme to accept deliveries of concrete truck mixers to exact timings and other construction materials.
- If errors are made during construction, remedial actions often involve major demolition operations.

For traditional steel frame projects, construction can take similar timescales and often involves the following operations:

- Significant storage areas for a number of large hot rolled steel framing elements as this often cannot be stored within the building footprint.
- Hot rolled steel framed buildings are often formed from a number of differing construction materials to form the floors, walls, roof, façade and general fit out. A number of trades represented by different packages and teams are required which reflect the various construction materials used, often programmed to follow on from each other which greatly increases the site construction programme.

Site construction operations demand skilled tradesman to form elements from loose materials in an outdoors environment, instructed by traditional construction drawings and details. This involves a high level of planning and skill to ensure all processes are carried out safely to demanding timescales, without error and often in adverse weather conditions. Construction projects have a historically negative reputation for high levels of accidents and fatalities, mistakes due to human error requiring corrective measures, and projects delivered late and over budget.

A survey undertaken by Cornerstone Projects in August 2017 involving 170 construction companies, found that 85% of respondents reported delays in a recent construction projects and generally most contractors anticipate that up to 30% of their projects are subject to delays. They conclude that delays in construction projects are a major cause of escalating costs. Another study by the National Audit Office (NAO) in 2005, using modern methods of construction to build more homes quickly and efficiently showed highly prefabricated systems can reduce construction periods by 60% and requiring 75% fewer operatives on site.

Time spent on the construction, installation and erection of components on site is reduced due the pre-fabrication of components within controlled factory conditions prior to site delivery. The components vary from individual beams and columns, to integrated panelised systems with integrated facades, finishes and services, to complete building modules with all components across different trades installed with minimal manual site work to complete the final installation. Storage of materials on site can often be avoided altogether in a well programmed scheme as building elements can be lifted into place and constructed in one operation as it is delivered to site avoiding traditional site operations removing risks associated with site operations and allowing cost and time savings. Off-site manufacturing can eliminate time delays due to bad weather conditions on site, which is common in UK construction. For example, traditional in-situ concrete cannot be poured and cured in adverse weather conditions such as freezing cold or heavy rain, however off-site prefabricated concrete can be poured in indoor factory conditions at any time and can usually be erected on site in adverse weather conditions.

Off-site manufacture generally gives a certainty of programme as site activities which are more prone to error are removed or reduced, reducing risk of delays to the project, which is particularly useful for public sector projects with definitive deadlines such as school buildings. As components are constructed offsite, this results in an overall reduction in transportation and number of deliveries to site as well as a reduced site installation programme which result in less disruption to the surrounding infrastructure. Less time spent on site and less overall man hours can result in a reduced risk of accidents on site due to less manual labour.

Projects which comprise of offsite manufactured components are generally found save time to construction programmes whilst also providing a higher quality of construction, being designed to the same codes and standards as traditionally constructed projects. Faster construction periods can also result in earlier occupancy of a building and an earlier return on investment.

Two ACE members represent two of the largest off-site pre cast concrete suppliers who manufacture panelised units often with integrated services, finishes and facades. Both of these suppliers report that projects can be delivered on site up to 50% faster than traditional construction project, enabling a time and cost saving.

Fusion Building Systems deliver a factory produced, pre-insulated external wall systems using light gauge steel panels. They delivered Globe Works student accommodation project in Birmingham together with Waterman Group providing engineering services. The building is a new 520-bed student accommodation on Cliveden Street, featuring two blocks of five and 10 storeys. The structure comprised entirely light gauge steel pre-insulated panelised walls and floors being manufactured in controlled factory conditions with openings pre-cut and accurately located and installed by eight site personnel delivered on time to a condensed 35-week installation programme.

Two Fifty One, is a multi-storey residential tower in Southwark, London. An ACE member provided engineering design services, supporting another ACE member in delivering this DfMA scheme where 70% of the frame was manufactured offsite. Total workforce days were reduced by 60% and the overall programme was reduced by 120 days or 33% when compared to a traditional solution.

An ACE member delivered Manchester Airport's car park 26 weeks ahead of schedule; a reduction in time of 26%.

Precast solution	Man-hour saving per unit vs. traditional
Prefabricated manholes	50%
Precast concrete column	85%
Precast concrete twinwall	95%
Precast concrete lattice planks	65%
Precast hollowcore slabs	82%
Delta Beam	88%
Precast concrete facade panels	97%
Bathroom pods	81%
MEP service risers	86%
MEP service horizontal modules	60%
Prefabricated air handling units	75%
Prefabricated plant skids	80%
Summary programme savings	**23%**

Table 1: Grange University Hospital savings

Internationally, there are striking examples of the benefit of off-site manufacture. A modular school was installed in Seoul, South Korea in just four days, and in 2020 a hospital in Wuhan, China was constructed in just 10 days to quickly deal with the spread of coronavirus. The hospital was made up of prefabricated hospital components, "plugged in and stacked up".

Cost

In the UK, a notable example of the political implications of the cost of construction is the HS2 railway where the cost of the project has been highlighted by politicians and the media as a concern[18]. Nine out of 10 buildings worldwide run over budget and the average cost overrun is 51%, according to Bent Flyvbjerg, professor of construction at Saïd Business School. "The construction site has to become an assembly-site," he said. "Until this happens, construction will be stuck in the Stone Ages as regards productivity."

An ACE member delivered Heathrow T7 MEP works under budget by £800,000 and nine weeks early through using off-site methods. That same member found £55m savings of overall anticipated construction cost for Manchester Airport's transformation programme.

Generally, a 7% cost reduction compared to traditional construction methods can be found[19]. McKinsey & Company analysis suggests that if leading real estate players are able to make the shift and optimize for scale, we will be able to realize more than 20% in construction cost savings[20].

Wider benefits and links to broader industrial strategy

The *Farmer Review* described aversion to change as one of the three key root causes of issues with the construction industry as "deep seated cultural resistance" to change[21]. Adoption of off-site manufacture represents an opportunity to show that the construction industry can undergo radical, beneficial change – and trail-blaze in regards for a wider transformation. This positive transformation would aid tackling another one of the key issues highlighted – poor industry image[22]. The holistic benefits of off-site manufacture; increased security, safety, working conditions; less risk, project failure and manual labour; mean that construction could shake off its image as behind the times and insular. This will have the knock-on effect of affecting the career decisions of potential workers and increasing the diversity of the industry over the long term.

Off-site manufacture also ties into the wider digital agenda: off-site manufacturing design is fundamentally linked to Building Information Modelling (BIM), another key technology in the future of construction.

BIM has emerged in modern times and is now utilised on the majority of construction projects within the UK and has been a tied to the surge in uptake of off-site manufacturing and modular buildings. For some modern construction projects which comprise entirely of off-site manufactured modules, they are made viable through the implementation of BIM rather than relying on traditional construction drawings. Collaboration of design elements and virtual construction processes can be carried out into an offsite manufactured solution prior to fabrication reducing errors in both the design process and site construction process. Off-site manufacture standardises building elements encouraging automation, reducing errors throughout the process and introducing efficiencies. Risks are reduced by providing a certainty of construction programme due to the implementation of BIM, resulting in less site errors and quicker site construction.

Traditional construction is often roughly programmed with contingencies to cover delays whereas off site manufacturing requires a more involved "just in time" approach as delivery of materials and erection happen simultaneously, therefore logistics are critical and drives the project. Sophisticated projects utilise 3D BIM models on site in place of traditional drawings which requires site workers to be upskilled. Each component of the BIM model delivered to site can be tagged and tied into the construction programme with component tracking and RFID tagging enabling the status and real world location of each component to be identified, reporting If it is under manufacture or its location en route to site and its expected impact to programme.

Off-site manufacturing can widen economic/employment benefits of construction by generating more jobs remotely from the site. It can create specialised manufacturing jobs away from main hubs of construction activities (such as large cities) increasing opportunities for upskilling and employment in other parts of the country. Make Modular, a recently established trade body created to promote the off-site housing sector, believes MMC can introduce up to 50,000 flexible future economy jobs where they are needed in the UK.

Sustainability

According to the UK Green Building Council, approximately 10% of the UK's CO_2 emissions are directly linked to construction, with cement production alone accounting for 8%. The construction industry carries a heavy burden of the UK's emissions.

According to ACE research, off-site construction requires less heavy machinery and less energy. Transporting the finished product to the site also uses minimal vehicles, and wastage is minimised, as material requirements can be more accurately calculated, allowing the company to make savings by buying in bulk.

Reducing workforce on site also reduces the requirements of temporary site facilities and its associated environmental impacts. One of the most obvious sustainability benefits of Off-site manufacturing is the reduction in waste produced on site. Research claims this can reach 70% to 90% reduction[23]. It can also be said that overall waste associated with a given component manufactured off-site is reduced since the processes and infrastructure put in place in a manufacturing plant are recognisably less wasteful than a building site. Some manufacturers claim waste is limited to 1.8% of overall materials used in the manufacturing process of building modules[24].

The use of off-site manufacturing can greatly impact traffic movement to/from site. The number of trips can be reduced as there is less raw materials being delivered to site. Overall congestion and associated pollution can be reduced by up to 20%[25].

It is widely recognised that Off-site manufacturing can deliver better quality materials and engineering systems; this results in better performance-in-use and potential reduction in energy consumption and carbon emissions. Better building envelope airtightness and factory-based commissioning of services are some characteristics of Off-site manufacturing components that will result in improved operational energy performance of the building.

Reducing operational downtime

An onsite build can severely test the patience of those unfortunate enough to live in the vicinity. Apart from the noise and air pollution of heavy machinery and equipment, construction and delivery vehicles travelling to and from the site can cause traffic delays and block parking spaces and access routes. This is a particular problem in constrained urban areas. Furthermore, construction works and cranes never look pretty and can be an eyesore for a long time. Moving construction away from the site and into a factory will be a great relief to local residents.

Health and safety

The factory is a far more predictable setting than the physical construction site, which eliminates the variables of weather and visibility. Having the conditions be the same every time makes errors much less likely. Most of onsite construction's most dangerous hazards: like fall from height and equipment accidents, are not an issue in the factory.

As outlined beforehand, an ACE member describes how Liverpool Street Crossrail saw large health and safety benefits compared with the similar project at Tottenham Court road station.

RISKS

Key uncertainties in the future of off-site highlighted by ACE membership

Risks of transport to site

There is a significant limiting factor to off-site manufacturing which is transport. 12m x 2.5m x 3m high is a standard container size, which limits the dimensions of large components, be them cladding, structural or building services modules.

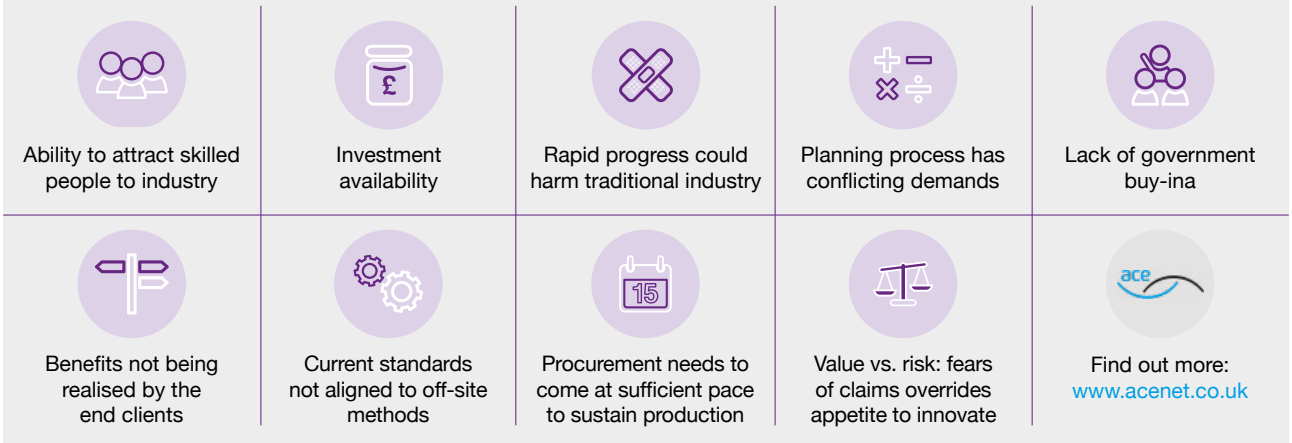
To allow safe and economical transportation to site, smaller components should be prioritised, utilising a modular approach to achieve larger scales. There are a number of IT companies and manufacturers who have had attempted containerised data centres for example IBM, HP, Schneider, and Eaton. None of them have been successful, primarily as they have had to keep to a small size to suit transportation limitations.

When using a modular/volumetric (rather than component) approach to off-site manufacturing, transportation limitations are higher. Offsite manufactured volumetric components tend to be larger, 'empty boxes' which are less efficient in transportation when considering total material volume or weight per trip[26].

It is common for additional structure and protection to be included in off-site manufacturing components to allow for safe transportation and lifting. In building services, for instance, off-site manufactured containers generally need to come in skids and/or structural frames to ensure integrity during transport. Whilst this can compensate for some practical site uncertainties such as slab unevenness[27], this additional structure has to be accounted for in terms of cost as well as overall weight and spatial allowance on site.

It is paramount that the additional space and logistics are considered at the earliest design stages to allow integration of off-site manufacturing, i.e. implementing design for Manufacture and Assembly (DfMA) methods.

Additional risks highlighted by ACE membership



Barriers to adoption

Construction decisions are often seen as short-term investment decisions – but with building, longer term strategic views are required. Traditional procurement and contract mechanisms do not allow for this more strategic view.

Planning process needs to change to recognise the full potential of modular. Many clients and planning authorities have conflicting demands which can stifle the potential for modular solutions. The Highways sector, for example, is still stifled by a compliance culture – standards and fears of claims overrides the appetite to innovate and challenge the norm.

There is a lack of integrated supply chains driven by fragmented procurement and a lack of early off-site contractor involvement at concept, which is where these contractors need to be involved in order to enable benefit. The traditional design paradigm is still in vogue – things are improving but this needs accelerating. One approach to would be to stop seeing use of off-site manufacturing as an 'all or nothing' decision. It can be introduced into projects with smaller and more manageable goals. Making wholesale change to methods of designing, procuring and constructing is challenging. It would be easier to introduce off-site manufacturing into discrete areas of projects and pilot-study these to learn and develop improvements. All sectors could participate in this and could be incentivised to do so. These goals could also be linked to other aims, such as reducing carbon.

The role of the design community is fundamental to improving understanding of the potential of off-site manufacture. Many stakeholders assume that while off-site may have some theoretical benefits in terms of cost savings it inevitably stifles creativity and innovation and will lead to bland one size fits all assets. However modern advances in digital design techniques and the creative skills of the design community mean this is simply no longer true. Innovative, attractive well-designed buildings that enhance the experience and productivity of those who use them are commonplace can easily be combined with off-site manufacture.

Until now the use of off-site manufacturing has been a side-issue trend that has grown in particular sectors where the blockers are not over-riding. As the Farmer report expresses well, we are now starting to see some of our common challenges facing the construction industry coming into alignment, with off-site manufacturing being able to address these challenges. Off-site manufacturing has moved from being an interesting trend in certain sectors to be a potential solution to many of these challenges.

To continue to facilitate this we need to address the remaining barriers. The recommendations of this breifing indicate how this can be achieved.

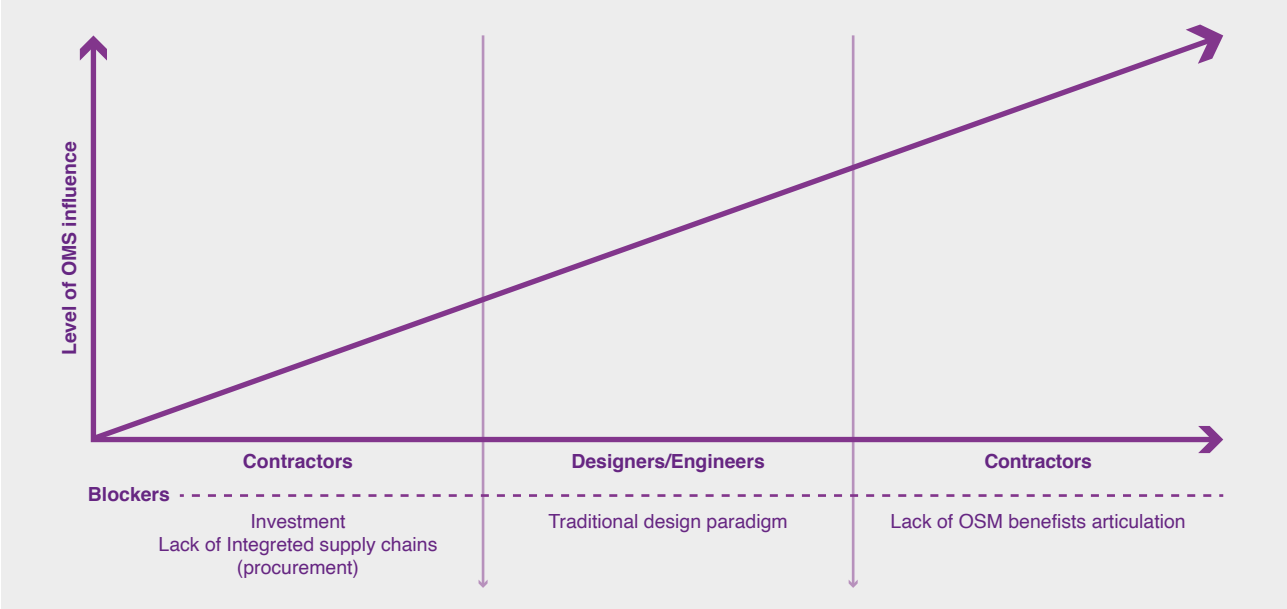


Figure 4: Blockers across the supply chain

If we don't address this opportunity, it could be lost

Modular construction alone represents a market estimated to be worth over $175bn by 2025[28] and the UK is not placed to capture this, with the Nordics, Japan and South Korea as global leaders[29]. Off-site construction offers an opportunity for post-Brexit Britain to differentiate itself. The Government has a unique opportunity to assist the UK industry become world leaders in an exciting, cutting-edge technology which has applications all over the globe.

REALISING THE BENEFITS

Some barriers have already started to be addressed by the construction industry. These include the advancement of digital technology and its uptake. However, work still needs to be done to make the wider use of off-site methods viable for construction. This can be categorised into three main areas:

- Creating consistent demand.
- Procurement changes to facilitate efficient use of off-site.
- Adopting a more standardised component-based approach to off-site that creates potential for wider application.

The Government can, and is, helping to enable change across all three areas. The work led by the Infrastructure and Projects Authority (IPA) is an example. In February 2019 the IPA asked the industry via its Proposal for a New Approach to Building: Call for Evidence, to consider Platform Design for Manufacture and Assembly (P-DfMA) and to suggest how the Government can encourage the adoption of this approach on its capital schemes. Engagement with the industry such as this should continue as the use of off-site and P-DfMA principles develops.

The involvement of five major government departments is already generating change and the use of procurement models that create alliance partnerships to deliver capital programmes is a positive shift. The recent Highways England Smart Motorways procurement is an example.

To enable the momentum to be maintained by the industry, in the current low-margin contracting environment, it is important that the Government maintains these strategies and ensures that procurement continues to prioritise the use of off-site methods, focusing on incentives rather than penalties for adopting this approach. There would be merit for instance in further tax breaks on DfMA delivery.

Moreover, more targeted support at lower end and smaller scale adoption would also be welcome. This could include support for the manufacturers of components rather than just focusing on large players who gear their investments predominantly towards factories. There is merit in undertaking a capacity study for the availability of off-site options and working with suppliers to incentivise gap-filling.

Help could be given to smaller local government procurement departments to adopt off-site policies by aggregating. For example, enabling small residential urban plots across a few local authorities to be served by a group of off-site manufacturers.

Other key areas which need consideration now are the overhaul of technical standards so that they are appropriate for off-site techniques. Government should also consider standardising technical standards across government departments so that off-site techniques can be standardised more readily.

What is clear is that, this radical change to the way we build in the UK is not going to create change over-night: for this reason, it would be useful if government departments were to create 10 year plans for change and embed this new approach in their procurement strategies.

It is recommended that the Government articulates this through an overarching off-site manufacture strategy with:

- A clear vision.
- Ambitious objectives and goals.
- Well considered critical success factors.
- A time-bound plan with discrete milestones.
- Metrics to measure progress.

SPECIFIC ACE MEMBERSHIP RECOMMENDATIONS

Creating a consistent demand

- The construction and infrastructure sector should advocate the benefits of off-site manufacturing to all stakeholders – ensure that off-site construction does not have the unfair stigma of "restraining design".
- To call on the Government to allow funding towards the Construction Innovation Hub (CIH) and UKRI to display pilot demonstration projects across all facets of infrastructure for Off-site manufacturing.
- Policy that government departments ramp-up to buy 25% of construction projects using off-site manufacturing by 2025, with a default to use value-based procurement unless there is a good reason not to.
- Encourage volume confirmation of pipeline projects over sufficient timescales of work to drive ability for companies to invest.
- Promote to and engage with funders and insurers to ensure backing.
- Policy so that lenders cannot blanket refuse to finance off-site constructed buildings.
- Default to use off-site manufacture with the help of the CIH Value Toolkit kit unless there is a good reason not to.

Category	Example	Off-site strength of case
Hazardous location	Offshore	Very strong off-site manufacturing case
Operational environment	Railways / Airports	Strong off-site manufacturing case
Urban environment	London	Medium to strong off-site manufacturing case
Rural environment		Medium off-site manufacturing case

Table 2: Case for off-site in different scenarios

Procurement changes that facilitate efficient use of off-site

- Encourage HM Treasury to adopt and promote off-site manufacturing in procurement procedures across all government departments.
- Improve procurement models to support off-site manufacture.
- Review Town Planning process to achieve speed benefits.
- Encourage culture of innovation and disruption in public construction procurement: have innovation a highly weighted component of decision-making criteria.
- Early off-site manufacturing contractor engagement at concept stage / joint concept design.
- Specific off-site manufacturing requirements in procurement strategies
- Replicate what good looks like in other government departments.
- Widen procurement to include a wider range of indicators and measurements – off-site manufacture will begin to be more heavily favoured naturally.

Adopting a more standardised pre-manufactured component and module-based approach to off-site that creates a wider application potential

- Drive policy to support standardised pre-manufactured component and module-based approach.
- Establish standard approach to product IP protection.
- Government financed off-site training and qualifications for off-site construction skills.
- Establish political imperative for component-based approach.

ENDNOTES

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Project Speed Briefing

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