In association with

AN OFFSITE GUIDE FOR THE BUILDING AND ENGINEERING SERVICES SECTOR

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Acknowledgements

In creating this guide the authors and steering group have referred to many sources of information and organisations, both directly and indirectly and their help and assistance is gratefully acknowledged. In particular:

- Buildoffsite has contributed significantly with inputs to the sections on Glossary and Case studies, and its report “Offsite construction: Sustainability Characteristics” in June 2013 has provided information for a number of sections.
- Heathrow Airport Ltd (the former BAA) has continued to support the cause for offsite construction by allowing Nigel Fraser and Richard Kelly to contribute much that has been learned over the past decade and providing a case study.
- Crown House Technologies and the wider Laing O’Rourke Group have contributed significantly from their experience and processes.
- NG Bailey has contributed significantly to the case studies.

During the development of this guide the Construction Industry Council (CIC) in 2012 and the Royal Institute of British Architects (RIBA) in May 2013 have issued guidance for plans of work, which embrace processes that are compatible with using building information modelling in accordance with the UK Government’s BIM Strategy. This guide has therefore been produced in a way that maps onto these plans of work. This is particularly evident in section 5, ‘Making offsite construction work, ordered by CIC / RIBA (2013) project stage.’

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The majority of the "Tools" detailed in section 10 are reproduced here with the permission of Heathrow Airport Ltd (where the initial work was done on them) and the developers of the concept, Richard Kelly and Nigel Fraser, who have incorporated additional learning from projects. They have been re-aligned with the new CIC & RIBA project stages. Heathrow Airport Limited continues to use them as part of its Design for Safety initiative.

Pre-amble

A Standard of Workmanship

The standard of workmanship set by this publication is intended to be appropriate to most normal domestic and commercial installations and relates to good practice in installation and energy use without unnecessary elaboration. The BESA intends this to be a significant aid in producing installations that will, given correct operation and with proper maintenance, provide satisfactory service over many years. It is a guide to the adoption of processes for designing and delivering such systems.

For large buildings and those with unusual or special requirements, the particular requirements shall be agreed between customer and designer.

B Quality Assurance

This publication can be used as one criterion that will assist customers, in performing the important role of defining the standard of installation they require. The BESA anticipates that this publication will be complementary to quality assurance schemes and quality assessment schedules. Where forming the basis of an independent certification scheme, it represents Good Practice in standards of project delivery and system installation.

This publication relates to construction practice and projects in the U.K. and the Republic of Ireland. It is not intended for overseas work, however, some of its provisions will be appropriate or may form a basis for overseas work.

This publication makes use of terms "should", "shall" and "must" when prescribing procedures:

1. The term "must" identifies a requirement by law at the time of publication.
2. The term "shall" prescribes a procedure which is intended to be complied with, in full and without deviation.
3. The term "should" prescribes a procedure which is intended to be complied with unless, after prior consideration, deviation is considered to be acceptable.

Foreword

This guide is intended to provide practical support for the effective use of Offsite Construction methods focused on Building Engineering Services within the built environment. It recognises the wider interaction with other construction specialists, addresses how to deliver optimum solutions for our clients, and considers the frequently asked questions for this approach.

Significant developments in construction methodologies have taken place in the last few years following other industry sectors like energy, automotive, aircraft and shipbuilding. These changes have been driven by many factors such as client expectation, cost and programme certainty, improving safety, quality and legislation, especially environment, energy & waste. As we emerge from the longest recession period in a generation, during which the skills base within the construction sector has been significantly weakened, offsite techniques provide a way we can apply the right skills at the right time and place to ensure our clients' needs are met.

The guide is intended to be an interactive document which can be accessed via a broad range of media in bite size pieces, individual sections or read as a whole as an integrated philosophy. Its content will be of use not only to contractors but all those involved in the built environment including architects, engineers, installers and most importantly our clients. With such a wide audience, by necessity the guide covers the majority of areas those embarking on a construction project at any stage should consider without narrowly focusing on individual products or solutions. For some, offsite practices have become the norm for delivery of projects providing useful tools, case studies and the rationale behind the approach; and their input to this guide is gratefully acknowledged.

Methodologies for offsite construction will continue to evolve in the future and we can expect it to form an increasing proportion, both by value and content, of our built environment. Building Engineering Services specialists are therefore uniquely placed to offer increased value to all parts of the construction chain by embracing this approach.

Paul Hancock
Former Chairman, BESA Technical Committee

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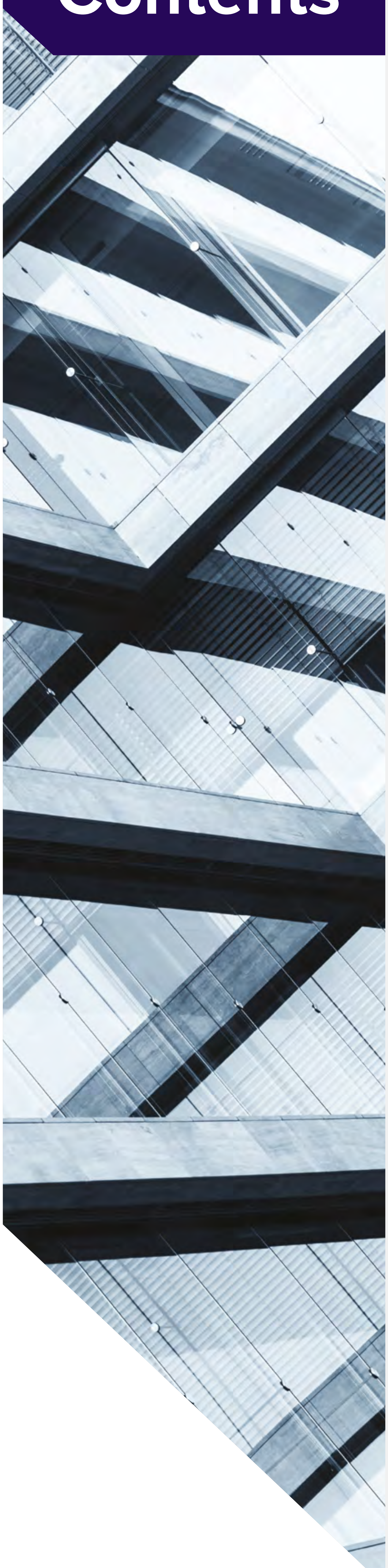


1.0 About this Guide

This guidance provides a practical overview of offsite construction, focusing on the information needs of building engineering services contractors working on projects involving offsite manufacture. It aims to place the installation requirements in the context of the overall construction process and enable effective delivery of an efficiently functioning system and building to the client.

It has been produced to assist those engaged in the design, installation, commissioning and/or maintenance of heating, ventilating, refrigeration, air conditioning, ductwork, plumbing, electrical, facilities services and energy management systems to follow a good practice approach when considering or using offsite fabrication, assembly and construction within their project.

This guidance is intended to enable and assist the contractor, non-expert client, facilities manager and building user to:

- understand the case for offsite construction
- appreciate the actions needed at each project stage to consider offsite construction and make it work for their project.

It is also likely to be of interest to other building services engineers involved in design, installation and commissioning as a tool that they may find helpful to use in discussion with clients, and provides other construction professionals with an accessible overview of the use of offsite construction and fabrication.

This publication is divided into two main parts:

- **Sections 3 and 4** explain the benefits of using offsite construction and the thinking behind the approach. Section 3 puts the case for using offsite construction ie the benefits and any downsides. Section 4 looks at what you need in order to use offsite construction effectively and when you should consider it.
- **Sections 5 and 6** provide a practical overview of the factors to be considered and actions required to make offsite construction work well, considering the tasks at each project stage in Section 5 and providing illustrative case studies in Section 6.

Read this to find out:

The publication answers the following questions, which can be used to help you find the most relevant sections to you:

Who is this guide for?	See section 1
What is offsite construction?	See section 2.1
Where is it used?	See section 2
Which projects is this most suited to?	See section 2
Why should I consider this?	See section 2.2 and 2.3
How easy is it to use?	See section 2
Why do the project team need to know about this approach?	See section 2.3
What are the benefits for me and for my client?	See section 3.0 and 3.1
What is the impact on the project programme?	See section 3.2
How does this affect project quality and building performance?	See section 3.3
What is the impact on health and safety for the project?	See section 3.4
Does this approach have environmental benefits?	See section 3.5
How will this affect project costs?	See section 3.6
Is there a downside – what do I need to watch out for?	See section 3.7
What are the risks?	See section 3.8
What do you need to have in place in order to be able to consider this approach?	See section 4
When do I need to consider this as a choice?	See section 4.1
How do I decide what is needed?	See section 4
What skills or knowledge should I or a client look for from a designer / consultant?	See section 4.2
How do I develop a strategy to integrate this into my work?	See section 4.3
Are there particular standards I need to comply with?	See sections 4.4 and 9
What skills will the workforce need?	See section 4.5
How do I decide on particular suppliers?	See section 4.6
What should I consider when choosing an offsite manufacturing location?	See section 4.6
What do I need to do at each project stage – is there a step by step guide linked to the CIC work stages or the RIBA Plan of Work?	See section 5
What questions do I need to ask?	See section 5
What information do I need to have and to provide / produce?	See section 5
What skills / tools do I need?	See section 5
Are there tools / checklists I can use?	See sections 4.2, 4.5 and sections 5 and 10
Are there examples I can look at?	See section 6 for case studies
Is there more information on the different types of services related modules?	See section 7
Where can I find more information?	See sections 8 and 10

A selected bibliography, including web links, is provided in section 8 for those who want further reading and guidance on the subject.

2.0 Introduction

Offsite construction of some kind is now used in well over 90% of UK construction projects. It is used for a huge variety of projects, from commercial to industrial, from health care to housing, from education to retail. Some offsite processes are now so familiar that we probably don't even think of them as offsite construction anymore such as pre-formed timber roof trusses or pre-insulated hot water cylinders complete with immersion heaters.

The proportion of the actual construction process now being carried out offsite can be up to 75-80% on some projects, with huge benefits in time and cost savings. To take a holistic view, cutting the time to delivery of the finished product can offer huge benefits for the client. To show what can be achieved look at this video of the 30-storey Ark hotel in Changsha in China which was built and then occupied in only 15 days.
http://www.youtube.com/watch?v=Hdpf-MQM9vY

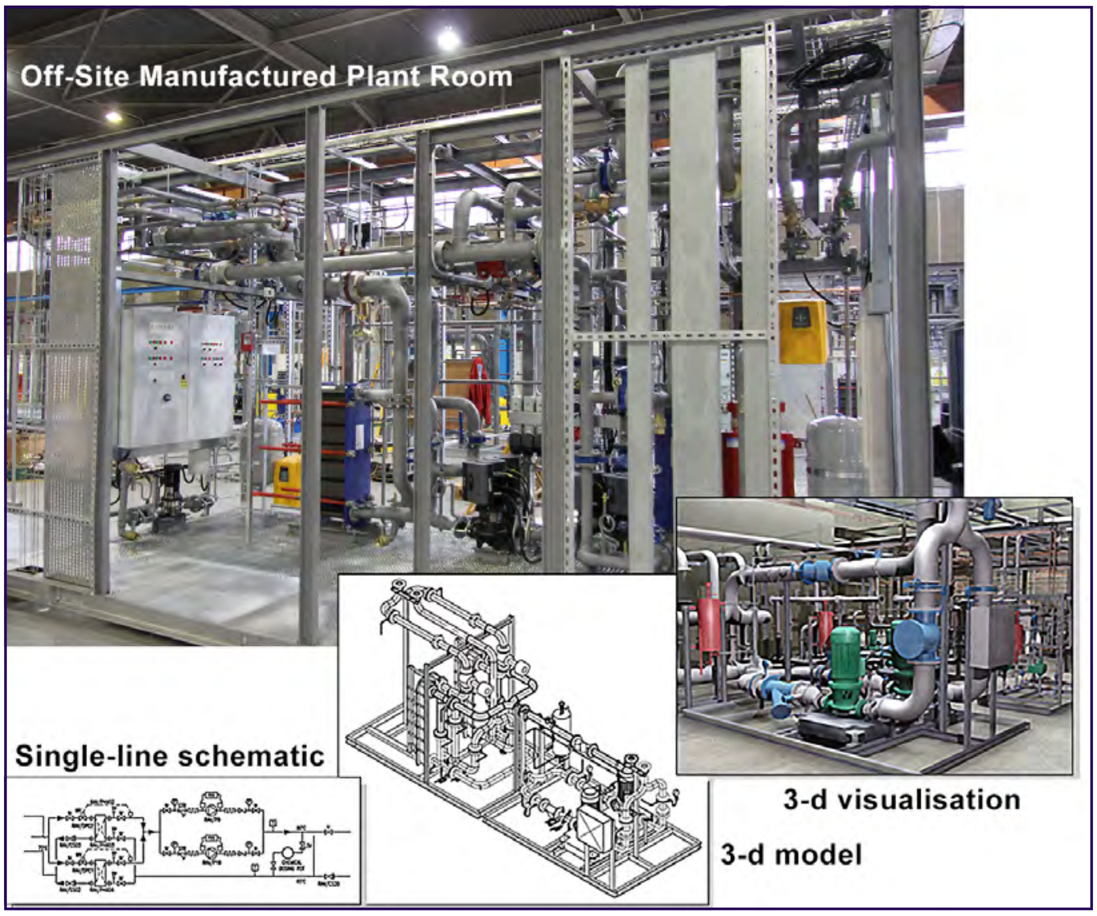
The predictability offered by offsite construction
Offsite construction offers improved control over two of the major headaches for the project team – delivering on time and on budget, as shown below, from the results of a long term study carried out by the RICS, and project analysis by a major modular building manufacturer.

	Offsite	Traditional on site
On time	96%	63%
On budget	94%	49%

(Source: Offsite figures based on Yorkon analysis between 2001 and 2006. On site figures from research carried out by BCIS on behalf of Royal Institution of Chartered Surveyors Construction Faculty – September 2004 – http://www.yorkon.co.uk/on-time-on-budget.html)

More recent figures show that offsite performance has improved further allowing one major supplier to deliver 99.7% of projects on time and budget; whereas overall construction performance has improved in some areas and worsened in others giving 34% of projects on time and 61% to budget. (Source: Offsite figures: Yorkon study analysing offsite performance 2014 – http://www.yorkon.co.uk/news-releases.html/215
Construction figures: UK Industry Performance Report 2012, Constructing Excellence/Glenigan)

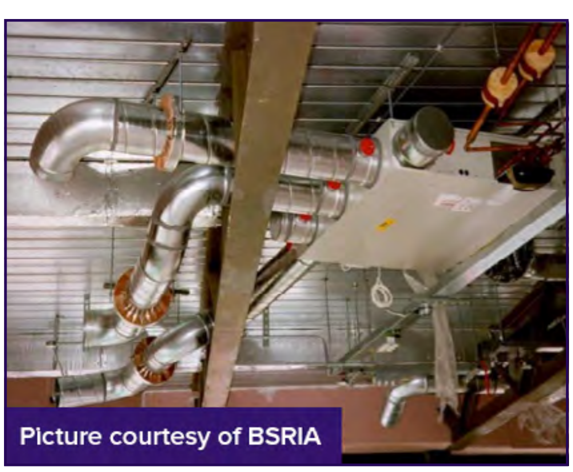
Within the building services sector the use of offsite construction is increasingly common, for example for offsite ductwork fabrication, preassembled and pre-wired pump sets, bathroom pods, preassembled and pre-wired fan coil cooling units with controls, complete boiler rooms and more.



It is also immensely beneficial for the building services sector due to the huge range of systems and components available. To give an idea of the magnitude of this, in a typical BIM model of a building there may be only 70 standard drawing components for primary structure whereas there would be in the order of 70,000 for mechanical and electrical services. The benefits of standardisation and offsite assembly are obvious as shown in the fan coil example below:

Fan Coil installation example

Fan coil unit in a traditional configuration with installation and connection done on site giving unique pipework and ductwork terminal configurations for each fan coil unit. Typically this would give a work rate of completing the pipework connections to two 4-pipe fan coil units per day (typically 50 joints per fan coil unit); and this would involve 12 different visits by 5 different trades (exclusive of testing & commissioning).


Picture courtesy of BSRIA

Whereas the use of a preassembled standard configuration using flexible pipework could give a work rate of twenty 4-pipe fan coil units per day (ref: 'Improving M&E site productivity', TN14/97. BSRIA).

Therefore you **NEED** to know about this, both to participate in this fast growing, efficient and innovative construction approach, and to be able to offer informed advice to your clients.

This online Guide from BESA provides a practical overview of the use of offsite construction for a variety of applications and different project types. It aims to provide BESA members, their clients and project team partners with a useful overview of this fast growing sector of construction. The online version of the guidance also enables quick cross referencing to other useful information, and allows the use of illustrative video material.

It will help to give you an understanding of the key facts involved in deciding to use offsite construction methods and materials and ways to make this work effectively.

This guidance will give the key outline and link you directly to fuller explanations on the internet where applicable (these are not official BESA endorsed links), and downloadable documents (in case you want to know more about any aspect). Additionally there will be references to key books and pamphlets that can give you better understanding of the subject – many freely available.

2.1 What is offsite construction?

Rather than worrying about all the various terms often used such as offsite fabrication, manufacture, assembly, production, construction etc this Guide will simply use the term offsite construction. The key issue here is not the detail of the process but the fact that it is carried out in controlled, clean and safe conditions, which are usually off the construction site. Hence the key word is simply '**offsite**'.

Obviously this can cover all sorts of combinations of manufacture and assembly, from the fabrication of ductwork sections to the manufacture and assembly of control components to the larger assembly of boiler modules or even complete plant room modules. It can even include some "offsite" construction in locations near the site or even on a clear part of a large site in dedicated clean, controlled temporary buildings. This video shows the use of prefabricated services risers form Heathrow Terminal 2A, http://www.youtube.com/watch?v=jK1Nc1bluac

Offsite construction is therefore the part of the construction process that is carried out away from the actual building site location. It is increasingly popular in the UK and overseas with increasing uptake of the approach. Therefore an awareness of offsite fabrication and construction, and the installation and project management needs of this construction approach, is essential for those involved in the design and installation of Building Engineering Services.

What is offsite construction?
Offsite construction can be simply defined as the part of the construction process that is carried out away from the building site. This can be in a factory or sometimes in specially created temporary production facilities close to the construction site (or field factories).

"...an approach to process in which the construction value added onsite is less than 40% of the final construction value at completion."
(Ref: Offsite housing review 2013).

Growing sector
Offsite fabrication and construction is a growing sector with rapidly changing technology and now accounts for at least 3-4% of the £100 billion construction sector annual, some £3-4 billion, and can account for up to 80% of the construction cost for some projects.

The key challenges
The key challenges for construction in the UK are to deliver a quality end product (the facility) efficiently and safely. Therefore some of the major issues that can be addressed by the use of offsite construction are:

Delivery:
- building performance

Construction:
- productivity
- health and safety
- wastage
- quality

Offsite construction can reduce the risks associated with all these factors.

For example:-
- Productivity on site is 30% of that in factories – on average (BSRIA TN 14/97)
- The fatal injury rate for construction is approximately two and a half times the UK manufacturing average per worker
- Injury and related lost time on site is significantly greater than the UK average per worker
- Material waste on a typical 'conventional' construction site is 10 times that of industrialised factory norms (ref: WRAP)
- Rework on site can be up to 30% of site operative activity
- Factory CO_2 emissions and embodied energy for the same built process can be over 55% less

(Source 'Offsite Construction – Sustainability Characteristics' Buildoffsite June 2013; HSE report into health and safety in construction 2013 and HSE report into health and safety in manufacturing 2013:; 'Leaner approach shows its benefits' Health Estate Journal March 2011 & Martin Goss – Mtech Consult, unless otherwise stated).

Offsite construction is widely used
Offsite construction has been used for many years from the simple examples of modularisation of bathroom pods or boiler rooms to offsite manufacture of ductwork. However it can now extend to practically the whole construction project allowing rapid builds such as used for some of the fast food outlets like McDonalds and Pizza Hut, and the 30 storey Ark hotel in Changsha in China which was assembled on site and then occupied in only 15 days, reportedly by a manufacturer of air conditioning systems.

Offsite is not unique to building construction
Offsite methods have been used for many years in other industries including energy, automotive, aircraft and shipbuilding. These offer experience and demonstrate the many opportunities which can be delivered, often beyond those commonly thought of in the building engineering services field. These video links show some examples:-

- Queen Elizabeth Class Aircraft Carriers
  http://www.youtube.com/watch?v=DUbTA3lVyU0
- The London Array
  http://www.youtube.com/watch?v=O7b3Ev2Emyc
- The Airbus 340
  http://www.youtube.com/watch?v=D-Rf4GN4nwI

2.2 Why you need to know about offsite construction

Offsite construction can offer considerable benefits to both client and project team, by allowing savings in time and cost, improvements in productivity and a reduction in risk and in accidents. This is discussed further in Section 3.

Construction 2025
The government launched the industrial strategy for construction, Construction 2025 in July 2013. Developed in partnership by government and industry, it sets out a vision where by 2025 construction has been radically transformed.
https://www.gov.uk/government/publications/construction-2025-strategy

The strategy has some bold joint ambitions for 2025:
- 33 per cent reduction in initial costs and in whole life costs;
- 50 per cent faster construction;
- 50 per cent lower emissions;
- 50 per cent improvement in exports.

"We will not achieve these ambitions by making small, incremental changes; the task requires the industry to do things very differently. We are talking about an approach to design, manufacturing, assembly and performance in-use that does not recognise poor quality or poor productivity. An approach that assumes zero accidents, and an approach where the use of BIM, Lean construction and the intelligent use of quality offsite solutions becomes the norm."

Peter Hansford, Government Chief Construction Advisor, Foreword to the BuildoffSite Yearbook 2014-15

2.3 Why it matters for the project team

In an increasingly litigious culture, the importance of delivering the right product on time and to budget cannot be over-emphasised. Projects are increasingly subject to over-run penalties and the cost implications of errors, rework and delays affect not only performance but also impact on PII (Professional Indemnity Insurance) costs and on company running costs and viability. Managing risk within projects is essential and good business practice. The use of offsite construction can assist with this goal, which is why it is essential for BESA members to be adequately informed on this approach.

The client needs to be aware of the benefits and implications of this approach at the inception of the project in order to make informed decisions.

The designers need to know as the use of offsite construction will affect design choices and decisions. This is not a process that can be added on after the design has been finalised. Design for manufacture and assembly, design for installation and design for operation are essential for success.

The contractors and sub-contractors also need to be aware of the options and benefits and provide their expertise at an early stage of the design process in order to maximise the efficiency benefits of this process.

The manufacturers and wider supply chain need to know the intent and so clearly communicate the options and limitations of their products, assembly methods or systems in order to ensure unrealistic choices are not built in at early stages and factory capabilities and capacities are available.

3.0 The case for offsite construction

Offsite construction can offer considerable benefits to both client and project team, by allowing savings in time and cost, improvements in productivity and a reduction in risk and in accidents. This section discusses and quantifies these benefits, and the risks and unintended consequences, enabling a clear and realistic assessment of the suitability of offsite construction for a particular project ie the “Why should I consider this? What are the benefits and risks?” It also proves material that can be used to explain the benefits to clients or to other members of the project team.

Some key benefits of using offsite construction are:

- A clear, rigorous and complete design process is required at an early stage, which encourages clear design responsibilities and a unified approach
- It supports standardisation and the use of common details which can reduce or remove the use of onsite customisation
- Management of the onsite activities can be streamlined with fewer trades and materials to manage and a shorter project duration
- Increased productivity on and off site
- Testing and commissioning of many M&E assemblies and modules can take place in clean and protected manufacturing facilities rather than on site
- The risk of accidents and injury is reduced
- Waste is substantially reduced
- Quality is improved with reduction of post-handover defects and rework
- Programme certainty due to the removal of site based unknowns
- A more sustainable approach due to the reduction in carbon footprint and reduced impact upon local environments.

All of these create opportunities to reduce project costs.

3.1 Client drivers

Key Points

1. Know your client. This may not be as evident as it first seems. In this context consider the organisations involved in developing and exploiting the output from the project.

2. Understand the context of the project. What is the client's business? What are the business outcomes they are aiming to achieve? What operational risks do they need to manage during the project? Identify opportunities to add value for the client.

1. Know your client.

In this context the term client can have several meanings, including the:

- End user of a facility
- Facility manager
- Owner
- Developer.

2. Understand the context of the project.

Clients usually have a business or organisation to run for which the business outcomes are often more significant than their interest in how a facility is constructed. The business context therefore needs to be understood when determining what value means.

Why might a client get value from more work being carried out offsite? Aspects that represent value to a client can therefore be many and varied, eg:

- Ensuring safety of personnel
- Capital, operating and decommissioning costs
- Programme duration & impact on operations
- Programme certainty
- Predictability of cash flow, including borrowing costs and rental income
- Quality certainty
- Bringing forward the opening date for the facility
- Ability to relocate the facility
- Temporary classification for business rating
- Impact on adjacent operations, EG at airports or in hospitals and prisons
- Timing – limited working window, minimising transport network possessions or using school holidays or avoiding impacts on Christmas trading
- Reducing the number of personnel on site (EG for security reasons).

To take these into account requires consideration of the economics of the project as a whole, not just substituting component line items in a cost plan.

That said the price of the project to the client is always important. Fortunately, when a holistic assessment of the economics is carried out, taking work offsite has significant potential for reducing costs and therefore ultimately price. (Refer to case studies in Section 6).

A well conceived project with the appropriate offsite content may therefore offer both enhanced value to the client, enhanced reputation for quality for the designer and competitive advantages to the supply chain.

3.2 Project programme

Key Points

- Offsite construction can reduce overall programme time and build time and substantially cut the time and man hours on site
- Quicker project set up (mobilisation) time on site
- Concurrency of more activities
- A different approach to commissioning systems
- Quicker site demobilisation & clean up
- Traditional sequencing can be restructured so modules are installed at a much earlier point thus reducing trade interface issues
- Time critical projects such as health and education buildings can be delivered with time certainty
- Time on site and therefore disruption to the local community or the rest of a client's business is substantially reduced
- Project risk is reduced. Consistency and quality is improved. Less time buffer needed in the plan
- Rework is reduced
- There is better control of quality and better control of time schedule
- Additional time is required at the beginning of the project to integrate an offsite construction approach and involve the supply chain
- A more holistic strategic approach is required to look at programme management
- An early design freeze and no subsequent variation or design changes should be the aim of all the project team.

Actions

- Set up proper programme management with client buy-in
- Set up strategic and effective supply chain management
- Communicate clearly defined project objectives to all parties involved, including site operatives
- Review sequencing and duration of activities for an effective programme.

'On time and on budget' ?
34% of "traditional" on site construction projects are delivered on time and 61% to the agreed contract sum **(UK Industry Performance Report 2012, Constructing Excellence/ Glenigan)** whilst one major modular supplier claims that over 97% of its building projects using offsite construction are completed on time and on budget.

A key driver for the use of offsite construction is the reduction in programme time it offers together with greater certainty of build time, enabling projects to run on time to meet client requirements. If adopted early in the design process it can cut build times in half depending on the project.

The reduction in programme duration is the result of several different factors, including:

- The reduced need for project overheads reduces the project set up (mobilisation) time on site.
- The concurrency of activities allows the overall project schedule to be shortened, i.e. groundworks on site can be happening whilst major elements of the facility are commencing offsite
- Higher productivity rates in factories
- The on site commissioning phase can be shortened (due to factory testing)
- On site commissioning may be started earlier and more easily done on a zone by zone basis allowing a progressive commissioning of the overall facility
- There is less equipment and facilities to be removed from the site at the end of the project.

With proper programme management and effective communication across the supply chain exact construction times can be given enabling time critical projects such as health or education buildings project to be delivered on time. In addition reduced time on site can have a number of added benefits such as:

- Minimising disruption, noise, dust etc for local residents eg Anglian Water used prefabricated pumping stations cutting the onsite time from the previous 5 weeks to 2 days, a tremendous benefit as many are in residential locations. http://www.buildoffsite.com/pdf/081009__markenzeranglianwater.pdf
- Minimising the impact to the clients business eg at St Helens & Whiston Hospitals 90% of the high level engineering services were prefabricated, with 65% of the installation completed on the first site visit. During the build not a single clinic or operation was cancelled. Furthermore the hospital opened six months ahead of schedule and within budget. http://www.buildoffsite.com/pdf/Yearbook/bos_yearbook_2012_61pp.pdf (case study 3)

Both time and cost are reduced, largely due to the fact that building offsite 'in the factory' removes the unknowns and variables associated with the equivalent construction or assembly on site. Critical path time is substantially reduced as onsite and offsite work can be done concurrently, and indeed offsite work can be done in a number of different locations simultaneously. This approach also helps co-ordination between different trades. Less onsite staging, such as scaffolding, is required, and for shorter times. The impact of weather is less of an issue as work can continue offsite regardless of snow, rain and frost.

Additional time at the design stage may be required on complex projects to effectively co-ordinate activities. However the overall time saved more than compensates for this.

Risks to the programme are reduced overall as less time on site also reduces risk of accidents and improved quality of products reduces the risk of rework or not having the right components available on site in the first place. As risks are reduced, the amount of time buffer built into programmes to reflect them can be reduced accordingly and such buffers can be placed ahead of the critical path activities, further reducing the overall programme for the project.

Effective use of offsite construction requires a programme rather than a project management approach as strategic resource management across the various work packages is essential to achieve a common aim. It is a more holistic and strategic approach also enabling resource requirements to be seen across a number of projects and echoes the findings of the Egan Report which called for an integrated supply chain within construction.

Effective supply chain management and integration is key to achieving the time, cost and quality benefits of offsite construction. Manufacturers and installers need to be consulted at design stage, because the earlier in the process offsite construction methods are specified, the greater the time and cost savings, and the greater the environmental benefits. For example insulation sub-contractors are traditionally often several stages removed in the project hierarchy but their contribution is critical to project energy and sustainability requirements. Their involvement in the early stage of project development enables them to contribute their specialist knowledge to optimise the type and timing of insulation. For example in many instances both the required insulation and surface protection can be added in the factory rather than on site.

Example of offsite savings and benefits

Offsite construction methods used on HMP Oakwood, Featherstone, West Midlands including those for services and the Energy Centre (plant rooms) ensured the project was delivered to time and was judged to be substantially quicker to build than a traditional construction project saving some 76,000 man hours of construction activity eg:

- 12,500 conduits assemblies, including shower heads and drains incorporated within the precast concrete panels – saving 5,000 site hours
- 4,416 under floor heating mats incorporated within the floor panels – saving 1,500 site hours
- 240 prefabricated vertical risers with pre insulated ductwork and pre installed wiring looms – saving 32,300 site hours.
- 30 air handling unit skids including ductwork, pipe work, insulation, wiring and controls – saving 4,800 site hours
- 40 domestic hot water skids including pipe work, insulation, wiring and controls – saving 12,800 site hours

And also gave:

- only three reportable incidents in more than 2.7 million man hours worked
- record levels of reduced on site material wastage.

Ref: http://www.buildoffsite.com/pdf/Case%20studies/casestudy_hmpoakwood.pdf

3.3 Achieving High Quality and Performance

Key Points

- It is easier to achieve the design intent performance of buildings
- Offsite construction delivers better quality controls and hence better quality with far fewer snags and faster commissioning on site
- A factory environment and 3 simple rules facilitate high rates of productivity and the achievement and control of the quality of the product
- This can be extended to the site where preassembled modules are connected to each other and on site elements more efficiently
- Productivity in a factory is much higher than on a construction site
- In a lean construction system, the production rate in the factory will be matched to the required rate of delivery to site
- Avoid large batch sizes, aim for one-piece flow for factory production.

Actions

- Identify or establish lean manufacturing supply chains (not construction in a shed)
- Apply the learning from lean manufacturing to the site installation processes.

Manufacturing and assembly in offsite facilities is able to provide the benefits of better quality products that fit well and rapidly on site. This includes a better fitting envelope to provide airtight facilities, pipework that has been assembled in controlled conditions and pressure tested before it comes anywhere near site and plant rooms that are fully assembled and tested before being divided up for transport.

The three rules If we use the following three rules as aspirations to be achieved then this will drive the correct practices and processes to be put in place when combined with a regime of continuous improvement.

The three rules for good assembly practice

1. All tools should be at arm's length and should work and be the right tool for the job
2. All components should be at arm's length and will fit right first time
3. The process should be controlled so that it is done the same way by everyone regardless of the number of ways there are to do it

Rule 1 ensures that the workstations are set out correctly for the range of activities that are to be performed there. It promotes the use of devices such as shadow boards and tools hanging on retractable lines in order to reduce the "waste" of searching. It also promotes the requirement for **total preventative maintenance** practices.

For example it may be that a particular workstation is for making M&E modules that will be assembled into a vertical distribution core. It is perfectly possible to set it up in a way that it can make a variety of modules (within the pre-defined parameters of the design) and to make them in the order that the project requires just as efficiently as making them in batches...

The big advantage of this **one-piece flow** approach is that it eradicates the "waste" of storing finished sub-assemblies. Also it is fair to expect that the design will require some modification in the assembly stages. Offsite manufactured facilities are not fully optimised mass produced goods after all. When the need for a modification does emerge then it can be made on the first module that it occurs on and then seamlessly incorporated into all future modules. The batching approach would lead to the very costly "waste" of re-work.

Ensuring that production stops when a design error occurs requires a workforce culture that understands their initiative is required to help solve the problem in a structured way that includes the management of the facility. Using their initiative to get around the problem, in the way practical people are want to do will result in a scenario where extra work is being done to every module without the knowledge of those that could do something about eradicating it.

Obviously it is much easier to develop the behaviour where the person on the tools feels empowered to stop production when there is a problem in an offsite facility where the workforce are all from one company and the results of the improvements can be seen more clearly. This element of continuous improvement process is more difficult to apply on site.

– Establishing these behaviours is part of rule 3 –

Rule 2 requires the supply chain to be properly capable (see section 4.5) and the design to be properly optimised for manufacture and assembly. It requires the workstations in the offsite facility to be set up and balanced for flow against the **task time** or **rhythm** that the project (generally the site assembly stage) requires. Again this requires the behavioural culture to contribute to the methods of fixing, and embellishing the design of the product so that it fits right first time.

Techniques for replenishing the workstations as they use the components that are triggered when pre-set levels are reached are good for promoting **one piece flow**. It is important that the internal processes are slick first before this is pushed further down the supply chain. The replenishment techniques (often known as **kanban**) can be something as simple as a twin-bin system for regular items or an email trigger for the bespoke items. Using a **water spider,** or operative with a trolley, to replenish each workstation on a rota is an effective method of ensuring each workstation is able to operate properly. Offsite manufacturing facilities should not be expensive, fully automated plants. Simple, cheap techniques are very effective.

Having a fully optimised delivery to the offsite facility and the workstations ensures that the amount of floorspace required is minimised therefore the amount of expensive production space can be minimised.

Rule 3 is all about establishing the behaviours outlined in Rule 1 into standard good practice. It also requires the inclusion of mistake proofing techniques either incorporated into the design of the product or in the tooling mechanisms. These can be simple devices which on the face of it add componentry and therefore cost to the product, but the benefits that are gained through right first time production outweigh this many fold.

Further guidance on good practice offsite and onsite assembly
The Lean Construction Institute, CIRIA, Constructing Excellence and others have published much guidance on this since the Egan Report was published.

The general approach to establishing an efficient M&E offsite facility as described above can largely be applied to the activities needed to assemble the output from the facility (and others) on the site. The Lean Construction Institute, CIRIA, Constructing Excellence and others have published much guidance on this since the Egan Report was published.

3.4 Health & safety

Key Points

- The fatal injury rate for construction is approximately two and a half times the UK manufacturing average per worker
- Injury and related lost time on site is significantly greater than the UK average per worker
- The use of offsite construction methods can potentially reduce the overall number of serious and fatal accidents on site
- Accident reduction has additional benefits in terms of both cost to society and to the reputation of the Construction Industry as an employer
- Offsite construction can also deliver improved working conditions to the industry and its workforce
- Onsite work must also be made as safe as possible
- Removal of man hours from site & increased productivity in factory reduce road accidents and accident rate/mile travelled.

Accident reduction

There were no reportable incidents in 120,000 man-hours worked to construct the Shepton Mallet NHS Treatment Centre using offsite techniques. There were only three reportable incidents in more than 2.7 million man hours to construct HMP Oakwood, Featherstone, West Midlands, using a number of offsite construction elements.

(Ref: Buildoffsite cameo case studies and
http://www.yorkon.co.uk/news-releases.html/159
http://www.buildoffsite.com/pdf/Case%20studies/casestudy_hmpoakwood.pdf)

“Traditional” construction can be a relatively dangerous activity. There are many tasks which inherently require risks to be taken such as working at height, in outdoor conditions, in the presence of heavy machinery, and operating mobile power tools, that are not present in other branches of industry.

Due to a number of initiatives, great improvements in site safety have been made over the past 20 years to the extent that the rate of overall and minor injuries is comparable with that in factories. However the rate of serious and fatal accidents on site is still some 2 to 2.5 times the rate in manufacturing industry, and absence rates due to injury are significantly higher than other sectors. (Ref ‘Offsite Construction – Sustainability Characteristics’ Buildoffsite June 2013; HSE report into health and safety in construction 2013 and HSE report into health and safety in manufacturing 2013). Therefore this data suggests that working in a modern factory is less likely to pose a risk of serious accidents occurring than working on a building site.

In addition, given that the use of offsite construction can considerably reduce the number of man-hours spent on site, sometimes to a small fraction of previous input; this can also potentially reduce the overall number of serious and fatal accidents on site. Case studies in the Buildoffsite Yearbook 2012 show that all the projects identified reduced time on site as a major benefit of using offsite construction methods. Actual savings in site-time vary but are typically in the range 50-75%. The number of people working on site at any one time is also reduced giving a potential total reduction in site hours of 60-80%. This could be expected to produce a pro-rata reduction in the occurrences of major injury and death...

There is also the cost to society of accidents and injuries in terms of health care, social care etc and the damage to the reputation of the Construction Industry as an employer. It is estimated that the cost to society of the annual construction fatalities and injuries is in the region of £700 million. The wider benefits of improving health and safety in the Industry are therefore substantial both in terms of cost and in terms of promoting the industry as a safe, caring and desirable place to work.

Scaffolding
The scaffolding of any building usually represents 1-2 % of cost. If a substantial offsite construction approach is used it is often possible to eliminate or at least greatly reduce the need for scaffolding, with consequent health and safety benefits – in the housing construction sector some 55% of fatal accidents are from high level scaffolding falls. (Source: Richard Ogden – Buildoffsite)

Comparisons between offsite and onsite operations in organisations involved in offsite construction show that often a greater emphasis was placed on layout and design for safety of workstation and environment in the engineering offsite manufacturing sector than the building sector. For example the offsite manufacturing sector placed greater emphasis on visitor control, the use of designated storage areas, colour coded delineated walkways and material storage areas.

There are many health and safety benefits to moving suitable work packages to offsite locations rather than carrying them out on site, including:

- Cleaner work conditions with less risk of trips, slips, falls
- Substantial reduction of the need to work at heights – by as much as 80%
- Manual handling and lifting reduced as materials are mechanically handled right to the workface
- Adequate working space rather than the confined spaces onsite
- Work can be carried out at safe workbench level
- Properly designed workstations with the right tools to hand and properly secured and stored
- Less onsite commissioning needed, reducing the risk of electrocution, etc.
- Better and safer control of ‘power-on’ for testing electrical components
- Safe all-weather working
- General welfare facilities better in the factory environment.

There are also, of course, substantial knock-on benefits in terms of the quality of the delivered product in these environments with less risk of contamination, better and easier quality control and the ability to inspect, test and commission under known conditions.

Offsite construction can also deliver improved working conditions to the industry and its workforce, which go beyond just health and safety factors, including improved job security, and improved opportunities for skills development.

Onsite work is of course still required and must also be made as safe as possible. As the modules delivered to site from offsite construction will tend to be of considerable size, usually over 6m in length, mechanical handling becomes essential, which actually also makes this a safer operation by reducing manual handling on site. It is however essential to ensure that the requirement for mechanical handling and the timing of delivery and assembling the components is properly planned.

Further Reading
Offsite Construction – Sustainability Characteristics’ Buildoffsite June 2013 Health and safety in manufacturing in Great Britain, 2013 Health and safety in construction in Great Britain, 2013 Offsite Production in the UK Construction Industry – prepared by HSE: A Brief Overview, Stephen Taylor June 2009

3.5 Environmental impact

Key Points

The sustainability benefits of an offsite construction approach include:

- Up to a 90% reduction in waste compared to traditional construction
- A 60% reduction in vehicle deliveries to site (with additional congestion & pollution benefits)
- An 80% reduction in energy use onsite, 50% overall
- A potential 25% reduction in energy use in operation for the completed building
- Reduced road traffic – 1 truck to site is equivalent to some 38 white van deliveries

Definition of Sustainability
(Based on the definition adopted by the World Business Council): Sustainability involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Sustainable construction needs to perform not against a single, financial bottom line but against this triple bottom line. Source – Offsite Construction: Sustainability Characteristics June 2013. Buildoffsite
http://www.buildoffsite.com/pdf/publications/BoS_offsiteconstruction_130709.pdf

Offsite construction has a very wide range of sustainability benefits, which go beyond the immediate environmental benefits to include financial and social benefits. Studies measuring the environmental impact of volumetric modular construction compared to traditional construction methods show that offsite construction can typically lower the overall footprint of a project by around 35-40%. It can also deliver a 42% reduction in CO_2 and yield a 21% improvement in the use of energy for building and maintenance. (Source MTech)

The biggest financial benefits come from the shorter construction programme that can be achieved with offsite construction, giving reductions in financing costs. There are also significant cash-flow benefits that can arise from early completion and therefore consequent early occupation. This can also give considerable financial client benefits as early guaranteed handover and occupation could be crucial in sectors where business can be very time critical such as air-side buildings at airports, or for healthcare, educational or retail buildings.

More immediate environmental benefits come from:

- A shorter construction time which reduces site traffic and pollution
- More efficient use of resources
- Reduced waste
- Less energy use on site
- A more energy efficient final product.

Transport

Offsite construction can use efficient and more sustainable methods of transport, such as rail, ship or barge. For example barges were used to transport construction materials to the London Olympics site. Where road transport is used the use of offsite construction can result in between 70-90% fewer vehicle deliveries and other traffic movements to site compared to traditional building methods. This delivers savings in resources but also has the added benefit of reducing noise, pollution, and congestion around the site.

Resource management & waste reduction

Resource use (materials, energy and water) is an increasingly important component of both cost and environmental impact for a construction project. Resource efficient construction is therefore crucial to a sustainable approach. This can be achieved by co-ordinated supply chain action utilising effective resource management planning, and can be supported by a range of tools and initiatives such as offsite construction as well as BIM and logistics solutions.

Traditional construction can be very wasteful, with waste not only of basic materials but also of energy and water, which can amount to some 3-5% of the construction cost. Waste reduction is therefore another significant sustainability advantage of using offsite construction. Research conducted with the UK Government's waste reduction department, WRAP (Waste and Resources Action Programme), shows that factory-based construction methods can reduce material waste by up to 90%. This is largely because design for manufacture ensures that the processes for ordering and cutting materials to size in the factory are much more controlled giving reduced wastage; and waste collection, sorting, and re-cycling is easier to organise.

Action to reduce waste can be taken early in the project cycle – for example the design team can consider how to reduce waste production as part of the design process. Now that the Site Waste Management Plan Regulations require a waste forecast by law in England (Site Waste Management Plan (SWMP)), this provides the opportunity to include and integrate this in the early project stages so that designing out waste (DoW) is considered along with other approaches such as Design for Manufacture (DfM) etc. Contractor input can be very beneficial to advise on suitable approaches.

WRAP information

A lot of useful information on reducing waste is given on the WRAP website (Waste and Resources Action Programme) **http://www.wrap.org.uk/category/sector/construction** They produce a downloadable guide **"Designing out waste: a design team guide for buildings**", which includes discussion on:

- Design for reuse and recovery
- Design for offsite construction
- Design for materials optimisation.

Less energy use on site

Shortening the onsite programme results in fewer resources being used onsite. Energy use is estimated to be around 70-80% less used in site offices and general construction activities (40-50% NET adjusted for factory).
(Source: **'Offsite Construction: Sustainability Characteristics June 2013'** Buildoffsite)

Energy in use

Offsite construction can deliver better building performance for the finished product with reduced energy-in-use because the build quality tends to be better and there is reduced opportunity for human error. For example improved fabric and structural quality can give reduced heat loss, improved energy efficiency and air-tightness, and improved acoustic performance. Similarly building operational efficiency can be improved – for example preassembled and commissioned M&E can deliver test and operational performances much closer to the target than those which are assembled and commissioned onsite. Both of these can result in improved EPC/DEC/BREEAM ratings which can be a significant addition to the building's commercial value.

References / Further guidance

- Offsite Construction: Sustainability Characteristics June 2013 Buildoffsite
  http://www.buildoffsite.com/pdf/publications/BoS_offsiteconstruction_130709.pdf
  http://www.wrap.org.uk/category/sector/construction
- Buildoffsite Year book 2014 – Sustainability section
  http://www.buildoffsite.com/pdf/Yearbook/bos_yearbook_2014_Nonmembers.pdf

3.6 Cost

Key Points

1. **Offsite construction can save significant cost.** To understand this it needs to be evaluated in the overall context of the project, including the beneficial impacts on project duration and risks.
2. **Evaluating cost benefits early in the design process.** To enable early decision to adopt offsite.
3. **IMMPREST™ – The Interactive Method for Measuring Preassembly and STandardisation benefit in construction.** A toolkit designed to facilitate benefit assessment when a decision needs to be made between two methods or systems of construction, typically onsite and offsite.
4. **Cost benefits associated with other advantages of offsite solutions.** The cost benefits include reduced costs associated with some of the other benefits of offsite solutions:
   a. **Materials** – Design for offsite solutions enables greater standardisation and the use of off-the-shelf products, both of which contributing to lower material cost and reduced material waste.
   b. **Productivity** – Labour costs typically constitute 30% of the overall M&E project costs. Therefore the increased labour productivity in a factory environment has a direct influence on the financial outcome of a project.
   c. **Time** – Even when the M&E installation is not on the critical path of the overall construction programme, cost benefits will result both from reduced commissioning programme and improved commissioning process.
   d. **Quality** – Factory components and assemblies are made under better quality control. They are also tested prior to delivery to site. Therefore, quality is better than if the equivalent products are assembled on site.
   e. **Health and Safety** – Activities carried out in a factory environment can be better organised and managed and have been shown to have better safety records, at lower costs when compared to site activities.
   f. **Site benefits** – Offsite reduces complexity and adds predictability to site activities, resulting in a number of associated cost benefits.
   g. **Waste** – Waste is reduced both at manufacture and on site. Research for WRAP has shown that offsite construction can reduce onsite waste by up to 90%.
   h. **Whole life cost** – Better quality reduces the operational consumption of the unit/component; reduces the occurrence of defects and the need for repairs.
   i. **Sustainability** – Sustainability benefits relate to other benefits of offsite, all of which have cost benefits.

1. **Offsite construction can save significant cost.** To understand this it needs to be evaluated in the overall context of the project, including the beneficial impacts on project duration and risks. It has been noted by many in the construction sector that taking work offsite add the overhead of using a factory. Whilst this is true, it also leads to much higher labour productivity, usually at lower pay rates than on site and less materials waste. It also leads to the reduction of a lot of overheads on the site, such as the size and duration of welfare facilities, site offices, scaffolding, equipment hire etc. Many costs are linked directly or indirectly to the overall duration of the project, (including the suppliers' overhead allocations). Taking work offsite can have a very significant impact in reducing the overall duration.

Similarly risks associated with traditional construction, such as those related to weather, quality control and the availability of materials become much less significant. That said, it introduces different risks, such as availability of factory capacity and the increased importance of good design integration. If an offsite element arrives on site and does not fit, the consequences may be very significant. These factors all lead to a need to take a holistic approach to costing such projects. For this reason, this section does touch on topics covered elsewhere in this guide.

2. **Evaluating cost benefits early in the design process.** To enable early decision to adopt offsite.

   One of the barriers for the adoption of offsite is the difficulty in evaluating its cost benefits early enough in the design process. If the decision to adopt is not made early in the process and design develops according to a traditional approach, early design strategies can become constraints to the adoption of offsite later on.

   Traditional methods for evaluating the benefits, particularly cost comparison tend to be based on direct resource costs. These methods do not take into account a number of relevant issues. Taking work offsite increases predictability, reduces the risk profile, the requirement for facilities linked to the number of people on site, (welfare accommodation, security clearances etc), temporary works and numerous other elements depending upon the context.

3. **IMMPREST – The Interactive Method for Measuring Preassembly and STandardisation benefit in construction.** A toolkit designed to facilitate benefit assessment when a decision needs to be made between two methods or systems of construction, typically onsite and offsite.

   As mentioned above, the key to effective benefits assessment is taking a holistic approach to it. The former DTI funded research at Loughborough University developed an approach called IMMPREST[4]. This considers a range of factors, including:

   - Cost
   - Time
   - Quality
   - Health and safety
   - Site benefit
   - Sustainability.

   It can reveal the hidden costs that traditional cost assessments tend to overlook.

   IMMPREST can be used in a number of different ways:

   - As a cost and value awareness tool for project teams
   - As a decision support tool early in the project
   - As an evaluation tool towards the end of a project to record where the costs have been expended
   - As a training tool for new teams
   - As a demonstration of value benefits by suppliers
   - As a rigorous method of producing business case studies

   Buildoffsite has commissioned several detailed case studies using this methodology. Each has confirmed a strong business case for taking work offsite.

   A number of proprietary database and BIM linked comparison systems are being developed that will make this easier.

[4] See www.immprest.com

The IMMPREST tool is now available as a free download beta version from:

https://offsite.lboro.ac.uk/

Look for "Value Offsite2 under the "Tools" tab.

Registration is required, but it is free and it also gives access to several other offsite-related tools and guidance.

4. **Cost benefits associated with other advantages of offsite solutions.** The cost benefits include reduced costs associated with some of the other benefits of offsite solutions:

   e. **Materials**
      Design for offsite solutions enables greater standardisation and the use of off-the-shelf products, both of which contributing to lower material cost. It also reduces waste of materials and off-cuts, which can be more easily managed and reused in a factory environment. Although the percentages vary, studies have found that at least 10% of the materials delivered to site are wasted[5]. Besides the purchase costs, storage and associated security measures, savings include also the reduced costs of waste disposal.

   f. **Productivity**
      Labour cost has a direct influence on the financial outcome of a project. Labour costs typically constitute 30% of the overall project M&E costs so increasing productivity has a significant impact on the value generated by the client's investment[6]. In factories, full year operational facilities in controlled environments increase labour productivity. Studies have shown that as much as 40% of the onsite manpower can be wasted[7].

      Offsite solutions result in improved utilisation of well-managed and appropriately skilled labour, both on site and in the factory, increasing labour productivity and reducing labour costs8. Furthermore, the cost of factory based labour is typically lower than the cost of site labour.

      Factory facilities can be located where skilled labour is more readily available and costs of labour, power, materials, space and overheads are lower. The key to handling the peaks and troughs of project related orders is to keep fixed costs down and use multi skilled labour so that the factory has a low break-even point and a flexible work force.

      Pop up factories, just set up for the duration of a project are also feasible on occasions. An example of this is the BAA fully serviced Corridor Product that was assembled in a temporary factory in Crawley.

5 (Egan 1998)
6 (Court et al. 2005)
7 (Egan 1998)
8 (Wilson et al. 1999)

g. Time

Reduced time on site can have marked and beneficial effects on contractor cash flow and the cost of finance.

Even when the M&E installation is not on the critical path of the overall construction programme, faster installation means that commissioning can start sooner. Commissioning is also improved as a result of factory testing of components and preassemblies. Cost benefits will result both from reduced commissioning programme and improved commissioning process.

h. Quality

Factory components and assemblies are made under better quality control. They are also tested prior to delivery to site. Therefore, quality is better than if the equivalent products are assembled on site. Better quality and more reliable assemblies reduce the need for re-work and result in fewer total resources being required. The resources required to rectify poor quality of site assembly is rarely quantified, so the cost benefits associated with the improved quality of offsite assemblies are rarely identified, although 'zero defects' is often acknowledged as a benefit of offsite. Less defects to resolve and more reliable system performance lead to both capital and revenue cost savings.

i. Health and Safety

Reduced on site labour means less Health and Safety risks as a result of site activities. The equivalent activities in a factory environment can be better organised and managed and have been shown to have better safety records. The accident rates in manufacturing are some 29% less for major injuries and 52% less for fatalities than in construction[9]. These figures are based on the number of major injuries and fatalities recorded per 100,000 operatives per year, therefore they can be improved further as more work is moved offsite. The cost of stoppages, injuries and investigations are all to be avoided.

f. Site benefits

Offsite reduces complexity and adds predictability to site activities. Site related cost benefits associated with offsite include:

- Reduced waste
- Reduced need for formwork, shuttering and scaffolding as offsite assemblies and components are often self-supporting
- Reduced labour, both direct and for coordination activities
- Reduced need for welfare facilities, security, control, etc.
- Reduced plant and tools
- Reduced on site storage, plus associated security and management
- Reduced water and energy consumption resulting from on site activities
- Reduced installation time, with associated quality control by the installer, contractor and on behalf of the client
- Reduced impact of bad weather at the construction site.

Many of these would be included in "project preliminary (or overhead) costs" and in the case of weather, the project risk assumptions and budget. It is therefore essential that when an offsite approach is compared with an onsite option, the preliminary cost and risk assumptions are reviewed in detail. They may be significantly reduced.

[9] (Krug & Miles 2013)

g. Waste

When comparing traditional construction with offsite, it is relevant to consider the different waste levels that arise at two main stages of activity, at product manufacture (including components and assemblies) and during construction. Traditional construction is very wasteful in material terms. Waste streams can represent anything up to 20% of the raw material tonnages, with 10% being a reasonable average figure across all building types. In money terms, this might represent some 3-5% of the construction cost, so it is a significant number.

Manufacturing processes, by comparison, are very much less wasteful, with figures in the range 1%-3% being regarded as the norm10. The material waste generated in a factory can be controlled and more easily managed. Off-cuts are reduced, packaging can be reused and recycled, breakages and remedial work are minimised.

By transferring activity from site to factories, waste is reduced both at manufacture and on site. Research for WRAP has shown that offsite construction can reduce on-site waste by up to 90%.

Waste reduction at the end of building life should also be considered. Offsite solutions make it easier to de-construct some building parts and re-use them elsewhere.

h. Whole life cost

Better quality, improved and rationalised design and manufacturing processes reduce the operational consumption of the unit/component; reduce the occurrence of defects and the need for repairs.

Offsite construction techniques have the potential to reduce energy-in-use because the finished quality of the buildings is generally to a higher standard. Examples include operational efficiency with preassembled/pre-commissioned M&E systems which perform much closer to their ideal specification targets than those which are assembled and commissioned onsite[11].

All of these have cost implications, which are often overlooked in assessing the benefits of offsite.

i. Sustainability

Sustainability benefits relate to other benefits of offsite. Some of these are:

- Faster construction (economic benefits)
- Enhanced performance, reduced snagging and defects (economic benefits)
- More efficient and less wasteful use of materials (environmental benefits)
- Reduced waste (environmental benefits)
- Reduced water and energy consumption resulting from on site activities (environmental benefits)
- Reduced road traffic movements (congestion and pollution, i.e. environmental benefits)
- Reduced operative travel (congestion and pollution, i.e. environmental benefits)
- Improved Health & Safety and working conditions (social benefits)

All of the above have cost implications, which are often overlooked in assessing the benefits of offsite.

[10] (Krug & Miles 2013)
[11] (Krug & Miles 2013)

3.7 Barriers and challenges

Offsite requires a different way of working by all involved, but once the new ways are understood and adopted, they bring significant benefits in processes, collaborative working and outcomes.

Key Points

1. **Early decision to adopt offsite.** This is fundamental to ensure the development of appropriate project strategies early enough in the project and tends to be driven by clients and their consultant advisers.

2. **Early design strategies.** To ensure the viability of offsite solutions even if the decision to adopt is made later in the design process.

3. **Procurement strategies.** To facilitate timely supply chain engagement and collaboration between consultants, contractors and manufacturers.

4. **Perception of higher costs.** The perception that using offsite is more expensive than traditional construction is possibly the main barrier to the adoption of offsite in the UK, and must be addressed early in the project. It can be a misconception.

5. **Lead-in time.** Lead-in time can become a problem if it is not understood early enough. It can become a barrier as a result of late decision to adopt offsite.

6. **Timely availability of design information.** The design programme should be developed to facilitate the implementation of offsite solutions. Traditional design processes tend to result in the late development of M&E designs, allowing inadequate time for detailed design prior to fabrication.

7. **Skills and equipment required to install larger components and assemblies.** Large prefabricated sections require heavy-duty cranes and precision handling to place in position.

8. **Negative impact on local employment.** There is sometimes the fear that local jobs will be lost, if the work done to fabricate the components is located in a place far away from the place of construction.

9. **Space.** There is a perception that additional space will be required, in fact generally the reverse is true as the installation is better planned from the outset.

1. Early decision to adopt offsite. This is fundamental to ensure the development of appropriate project strategies early enough in the project and tends to be driven by clients and their consultant advisers.

The intent to adopt offsite solutions from the earliest design stages is at the same time the most significant success factor and the greatest challenge for a project team. When the offsite option is initially rejected, but re-considered at a later stage, usually due to programme pressures, the design previously developed may not be suitable for offsite delivery; and may be at an advanced enough stage to preclude the necessary changes. The reducing scope for changes over the time scale of the project is well recognised[12]. Similarly, inappropriate procurement strategies may be in place that will compromise the efficient development of offsite solutions.

[12] (Pasquire & Connolly 2003)

Although late decision is often identified as a barrier to the implementation of offsite, most of the other frequently quoted barriers tend to be related, for example[13]:

- Inappropriate design strategies
- Inappropriate procurement strategies: package split across elements that should be combined for offsite delivery
- Perception of higher costs when compared to traditional solutions
- Lead-in time not able to be accommodated within overall programme
- Timely availability of design information.

2. Early design strategies. To ensure the viability of offsite solutions even if the decision to adopt is made later in the design process.

The challenge for designers is to adopt an early design strategy that will not prevent the later adoption of offsite solutions. The decision not to adopt offsite may be made early in the project, before the contractor is appointed and before the benefits of offsite are fully appreciated. In this case, it is likely that the traditional approach will be seen by the consultants as their brief and the default design strategy will be 'traditional design'. What if the default design strategy were 'for offsite'? I.e. always design adopting a discipline that clearly defines the services distribution zones and addresses the interfaces with other building elements so that the services can be installed at clearly defined stages as well as within clearly defined zones.

Consider that a traditional design is likely to become a barrier to the later adoption offsite solutions while design for offsite will not prevent a traditional approach to construction. In fact, the discipline required for offsite delivery will improve the traditional installation of M&E services on site by keeping the zones and interfaces with fabric and structure more clearly defined.

The design process should aim for early fixity of design and specification. Again, this is a strategy that can also benefit a traditional delivery approach. Adopting this strategy for design content and process, consultants will give their client best value, by not precluding the adoption of offsite solutions.

3. Procurement strategies. To facilitate timely supply chain engagement and collaboration between consultants, contractors and manufacturers.

Late decision to adopt offsite solutions can lead to inappropriate procurement strategies, i.e. the lack of consideration for how the M&E packages are going to be delivered early enough in the design process. In most cases, the successful implementation of offsite solutions will require a commitment to the supply chain earlier in the project.

A procurement strategy that separates elements of M&E services into packages may prevent the delivery of offsite solutions. This is the case when a number of services that share the same physical zone are split between distinct supply packages. Effective offsite solutions can be best achieved through the effective collaboration between consultants, contractors and suppliers/manufacturers – enabled by the appropriate conditions of appointment and procurement method, and by the early engagement of the M&E contractor(s).

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[12] (Blismas et al. 2005)

4. Perception of higher costs The perception that using offsite is more expensive than traditional construction is possibly the main barrier to the adoption of offsite in the UK[14]. Although this initial perception tends to change with the input of the M&E contractor, it can affect the decision to adopt offsite solutions, which is made earlier in the design process, before the M&E contractor is part of the project team. It is therefore important that clients and consultants develop a better understanding of costs associated with the benefits of offsite for well-informed and timely decisions. The adoption of an assessment tool such as IMMPREST is recommended.

5. Lead-in time. Lead-in time can become a problem if it is not understood early enough. It can become a barrier as a result of late decision to adopt offsite. If the decision is made early enough, lead-in time can be factored into the overall programme. The team can assess the implications for design, procurement and construction and develop appropriate strategies. The design programme needs to be developed to accommodate the required lead-in time for each M&E package, and the procurement strategy needs to take this requirement into account.

6. Timely availability of design information. The design programme should be developed to facilitate the implementation of offsite solutions. Traditional design processes tend to result in the late development of M&E designs, allowing inadequate time for detailed design prior to fabrication.

Traditional design comprises progressive development of increasing levels of detail until all details are defined and materials are specified. Who undertakes this and at what stage in the project varies, with M&E services tending to be detailed much later than structure and fabric elements and usually well into the construction phase[15]. If the decision to adopt offsite solutions is made after the initial design has been developed following a traditional approach, it is unlikely that adequate zones and interfaces will have been designed. By then, it may not be possible to change and complete the design information within the required timescale, which will have to accommodate also the lead-in time requirements.

While traditional designs may not easily enable offsite delivery, early design principles for offsite need not preclude a traditional form of construction. For this reason, this approach could be adopted more often, even before the team is confident about the business case for offsite. This could help overcome some of the usual design related barriers.

7. Skills and equipment required to install larger components and assemblies.
Large prefabricated sections require heavy-duty cranes and precision handling to place in position. The need for heavy lifting equipment is sometimes mentioned as a consideration against the adoption of offsite solutions. However, the predictability that offsite brings enables better planning of site activities, including the equipment and timing required for installation. With good planning, the use of heavy equipment, as well as other specialised tools can be adopted with great efficiency and contribute to high productivity of site activities.

Site activities should be planned at design stages and should inform the design solutions, in collaboration with the design consultants and manufacturers. Great improvements in productivity can be achieved by optimising offsite solutions through innovations in manufacture and site operations – including product and process standardisation, mass customisation and continual improvement.

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[14] (Goodier & Gibb 2005)
[15] (Pasquire & Connolly 2003)

8. Negative impact on local employment. There is sometimes the fear that local jobs will be lost, if the work done to fabricate the components is located in a place far away from the place of construction. Offsite solutions reduce activity on site and inevitably mean that there are fewer locals working on any construction project at any time. On the other hand, with shortages in locally available skills it is unlikely that traditional construction methods employ 100% 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[16].

9. Space. Despite allowances needing to be made for module supports, generally overall space requirements are comparable for both approaches. This is because modules are better detailed than traditional installations so all space issues are worked out before arriving on site in the most effective arrangement. Access to maintainable components is often improved in this way rather than relying on site operatives decisions, and for plant rooms in particular can lead to reduced footprints overall. Distribution within the building would usually use a proprietary support system to affix pipework, ductwork and containment so a frame for modular purposes will add little overall, and if combined with other elements may reduce the overall space requirement.

[16] (Taylor 2009)

3.8 Risks and Unintended consequences

Key Points

1. Timeline & planning

- The primary risks associated with offsite construction are really to do with the requirements to make it work effectively ie the time line for decisions; the appraisal and sourcing of the resources required and the workforce skills needed.
- Poor project planning can lead to problems with co-ordination and the correct sequencing of trades and to project delays

2. Design freeze

- The unintended consequences of using offsite construction may be a lack of flexibility and limited opportunity for customisation.
- The consequences of late design changes will be far more difficult and costly to accommodate than with conventional construction.

3. Clear information

- Poor, unclear or outdated information will cause confusion, delays and errors.

4. Resourcing

- There will be increased transportation requirements which need to be addressed logistically.
- There may be limited supply sourcing options. The number of suitable providers of offsite fabrication or components may be limited or there may be capacity or time constraints if they already have long order books.
- The location of suitable providers of offsite fabrication or components may be remote from the site thus creating transportation issues.
- The size and weight of preassembled components or modules may be a factor in transport logistics due to size and weight limitations on certain routes.

5. Skills

- Inadequate training of the workforce with respect to products, methods and time management can dramatically impact on site (and offsite) productivity and efficiency and cause delays and errors.

1 Timeline and planning

Inadequate initial site surveys can result in the potential risk of finding there is inadequate access, handling space and storage for the requirements of an offsite approach at an unacceptably late project stage. Poor project planning, organisation and management can give rise to problems with co-ordination and the correct sequencing of trades. For example on one project the glaziers had put up their scaffolding early – preventing the 6m long ductwork modules from being swung into an access position on each floor by crane as planned. Poor planning can also lead to delays if the necessary mechanical handling equipment, such as cranes or hoists, is not available when needed. Inadequate consideration of the requirements for onsite storage and handling of material, material delivery to point of use and lifting equipment can also impact on the project schedule and cost.

The size and weight of preassembled components or modules may be a factor in transport logistics due to size and weight limitations on certain routes.

2 Design freeze

For effective use of offsite construction the design work to incorporate this approach needs to be completed at an early stage and the design then frozen.

> **Design freeze**
> Designs need to be frozen at an early stage to allow effective use of offsite construction. Late design changes or variations would have undue cost and time consequences which can outweigh the benefits of using an offsite approach.

3 Clear information

Poor project documentation, information content and management (for example poor use of BIM / CAD, or poor or inadequately updated material databases of services and support mechanisms) can cause project delays and co-ordination issues. Poor drawings can prevent efficient routing and co-ordination of services and cause wasted time. Design intent needs to be clear to ensure repeat solutions are used not unique, labour intensive ones. Assembly information needs to be clearly communicated to site teams as project build approach changes both timeframes, resources and skills required at the point of installation. Any disassembly information unique to modularisation should be contained within the H&S plan.

4 Resourcing

There may be limited supply sourcing options for offsite construction as the number, location and capacity of suitable providers of the offsite work components may limit choice, or introduce additional time and cost factors eg due to transport from remote locations. However there are numerous capable offsite M&E manufacturers, well established in the UK.

5 Skills

Incorrect skills or inadequate training of the workforce impacts on operation, productivity and deliverables for the project. Unclear or unidentified targets, poorly communicated interfaces, lack of clear responsibilities and poor monitoring and control can all lead to poor quality, delays and errors. Team building, motivation and creating a shared identity with a common goal for the project are key to effective workforce management. Particular attention needs to be focused upon the interfaces between onsite and offsite work packages. Offsite construction requires systems integration and assembly skills.

4.0 Deciding to use offsite construction

This section addresses some of the organisational competencies required for the use of offsite construction ie the "What do you need to have in order to be able to consider this approach?"

It addresses the issues of when to consider the use of offsite construction within the process, the flexibility of approach needed, the quality procedures and standards required, the workforce skills needed and the requirement to find and assess suitable manufacturing locations and suppliers.

4.1 When to make the decision

Key Points

1. Early consideration. The earlier offsite construction is considered in the process the more flexibility there is.

2. The decision. By definition, if there is a site, there will never be a project that is 100% offsite. However, the optimum mix of offsite and onsite content can be arrived at by early consideration of the options. The project needs to be assessed holistically based upon the client's value drivers.

1 Early consideration

Consideration of how something may be constructed can be done at any stage of a design's development, but the earlier it is considered, the more flexibility there is likely to be,

Offsite advice is never wasted
Buildability/ offsite manufacture advice during early design stages can never be wasted on a project, even if an offsite approach is not progressed. The principles of a good and structured design process always add value to a project.

Where feasible offsite construction should be considered during the earliest stages of a project, before the option has inadvertently been precluded, allowing any benefits to be maximised, and risks minimised. This can help inform the procurement strategy for the project, key aspects of the contracts to be used and supply chain partners, as well as enable and influence the selection of a design team who are able to appreciate the design requirement to enable efficient offsite construction.

There are merits to designers working at an early design stage with offsite manufacturing suppliers, to ensure that buildability and site constraints are considered. This can also avoid wasted design time.

Time wasted due to late consideration of offsite construction.
An example (provided by NG Bailey) where time was wasted is the Birmingham Gateway project. Designers designed a "traditional" scheme but subsequently it was found not to be feasible to build around the station operation. Hence the time taken to produce that design was lost and further investment was needed in an offsite based design which satisfactorily addressed the operational needs. The lesson learnt is to consider offsite early on in the concept design stages to avoid taking traditional designs to too much detail.

2 The decision

This guide is primarily about building and engineering services; however, at the outset it is necessary to consider the project holistically to optimise the whole rather than individual aspects.

At the core of the offsite approach there is a need to understand what represents value to the client. What are its value drivers and how are these ranked? Can taking work offsite help achieve delivering better value in the context of the specific project?

For illustrative purposes, assume that the value drivers for the client are ranked as:

1. safely delivered,
2. adequate quality,
3. low price,
4. short programme duration.

In this context, it is easy to imagine taking work offsite as bringing benefits in each of these areas. The design team would therefore be advised to keep this option available by avoiding making decisions about the detail of a design before the offsite options have been explored. To do that the designer will need to consider how to optimise at least 7 major factors:

- The functional requirements
- The planning and aesthetic needs
- Design out waste
- Design for efficient assembly
- Design for efficient manufacture
- Design for commissioning
- Design for maintenance and reconfiguration in use; and increasingly
- Design for end of life.

The first two will be project specific and are not considered in this guide except in so far as they impact on the offsite processes. Design duties for building engineering services are well defined by BSRIA[1] (Design Framework for Building Services (BG6) 3rd ed. BSRIA 2012). Designing out waste is well covered by WRAP and BSI guidance and differences are highlighted between offsite and traditional construction methodologies. This guide therefore primarily focuses on design for manufacture, assembly, commissioning, maintenance, decommissioning and disposal or re-use.

By definition, if there is a site, there will never be a project that is 100% offsite. However, the optimum mix of offsite and on site content can be arrived at through a combination of designers:

- leaving the option open at the early stages of design (by avoiding the tendency to add too much inappropriate detail too soon); and
- choosing solutions to their design challenges that respond best to the need to deliver value as perceived by the client, whether that be the ultimate client or user of a facility or the next organisation in the supply chain. The detailed design will quickly close down the options but as long as these decisions respond to the same value criteria, the ultimate mix of offsite and on site content should emerge.

The client's value drivers may determine that this is arrived at before tendering for production design and construction. However, if the design is developed with a view to enabling offsite, prior to tendering, market forces may work on an unbiased basis. Contractors that favour either traditional or offsite approaches may compete effectively, (as opposed to designing for a traditional build and then requiring the offsite suppliers to reinterpret the design for their systems during the tender submission phase).

[1] BSRIA Design Framework for Building Services (BG6) 3rd ed. BSRIA 2012. Note: 4th edition due shortly

4.2 Assessing designers and consultants

Key Points

1. Select the right designer

A key part of deciding to use offsite construction is to find and assess suitable designers who are familiar with the requirements of offsite construction.

The following checklist has been found to be of use in assessing and appointing designers familiar with offsite methodologies and is especially useful for clients in selecting their professional teams or contractors within a design and build contract. It includes both open and closed questions to allow the respondent to demonstrate their depth of understanding of the field.

Assessment of designers and consultant capabilities

1. Define 'Offsite Construction' – what it includes and what it excludes
2. What are the limitations of offsite construction
3. Give examples of projects where you used offsite construction within your design
   This should include: a. Projects for this client/contractor b. Other Projects
4. How will you engage to maximise the offsite construction opportunities on this project?
   This should include:
   a. During outline concept design (maybe by others)
   b. Concept design
   c. Detail design
   d. Manufacture
   e. Installation
   f. Finishing
   g. Setting to work
   h. Commissioning
   i. Maintenance
   j. In use
5. Describe the benefits of offsite construction for:
   f. The company (eg a main contractor)
   g. Our clients
   h. Your practice
   i. Others
6. Describe your internal design processes and monitoring procedures to maximise offsite construction on a project.

   This should include:
   a. A offsite construction design programme
   b. offsite construction design deliverables
   c. Your internal training procedures around offsite construction
   d. Your internal and external briefing mechanisms?
   e. How do you demonstrate offsite construction development by utilising internal and external tools?
7. How do you manage innovation and change within the offsite construction environment?

8. How do you maximise integrated design across all disciplines?

   This should include:
   a. Specialisms
   b. Supply chain
   c. Other designers
   d. Manufacturers
   e. Competitors
   f. Multiple functionality

9. Which offsite construction product libraries and software do you currently utilise in your work streams?
   j. Core software versions and seats
   k. Proprietary plug ins and versions
   l. Manufacturer product families
   m. In-house applications and APIs

10. Introduce your team to us.

    This should include:
    a. Availability
    b. CVs
    c. Previous experience
    d. Regional & Sector experience
    e. BIM experience

11. Describe your approach to using proprietary products

    This should include:
    a. Standard compliance
    b. Design liability
    c. Vendor assessment

12. Have any of your projects and or products been externally assessed or certified?

13. Specialist services:
    a. Approach to prototype design
    b. Product design development & experience
    c. Jig and transport design
    d. Structural design for sub assemblies

4.3 Enabling offsite approaches

Key Points

1. For any given project the mix of onsite and offsite will vary.
2. Generic rules for designs that will enable offsite delivery can be developed for any project even if there is no early commitment to offsite delivery
3. There is an opportunity for M&E contractors to offer consultancy advice on 'design for offsite' through their relationships with design engineers and architects.

The difference between designing in a traditional way and designing for offsite is that in a traditional design the spatial relationships between individual components from different disciplines can be fairly bespoke or even arbitrary. There is no practical requirement for consistency, modularity, or for the spatial segregation of groups of components (or assemblies).

For offsite delivery, the components that can be preassembled offsite need to be identified in 'groups'. The definition of these groups and their interfaces with other building elements should be established as early as possible. The interfaces and connections of the components within the group could be seen as a detailed design matter, which can be developed once the detailed scope is known.

For any given project the mix of onsite and offsite will vary in response to a whole range of factors however often the option of offsite is determined too late or by chance which restricts the benefits available and increases project risk. As project delivery teams become more familiar with offsite methodologies this mix becomes more easily determined and optimised. Over time some teams, their clients and whole sectors have embraced and indeed pushed the boundaries of the possible.

It is always more efficient to define the scope of possible pre-assemblies at the earlier design stages. Applying design effort at this point means that design time subsequently is focused more clearly on meeting the brief rather than the' nuts and bolts' as the strategies, if not the detail, have been agreed.

Generic rules for designs that will enable offsite delivery can be developed for any project even if there is no early commitment to offsite delivery. The strategic decision required is to agree that the client does not want to preclude offsite delivery.

In fact, the design discipline involved in designing for offsite delivery can contribute to more efficient 'traditional' construction if this approach were to be chosen, i.e. if offsite delivery was not to be the eventual delivery option adopted.

At present, the difficulty is that the M&E contractor may not be part of the project team early enough to influence design strategies. However, the architect and M&E design engineers are. This presents an opportunity for M&E contractors to offer consultancy advice on 'design for offsite' through their relationships with engineers and architects.

Clients and/or contractors may be unwilling to commit to offsite delivery at early design stages. This tends to be because early in the project they are not sure that this approach will be cost effective. Unfortunately cost advice on alternative delivery methods, namely traditional versus offsite, is not readily available to inform early decisions. It is therefore important for clients, designers and contractors to understand that designing for offsite delivery does not preclude traditional construction while the opposite may not equally apply. In other words, if the intention is to keep one's options open, design should be for offsite delivery, not for traditional construction.

There is an opportunity here for M&E contractors to help up-skill architects and engineers in how to design for offsite. The benefits will be the greater adoption of designs that can easily be 'developed', as opposed to 'adapted' for offsite delivery. In the increasingly collaborative environment being created by BIM, efficiency of digital information creation and transmission will move away from silo approaches enabling the whole construction sector to offer best value.

4.4 Quality Standards & Statutory Compliance

Key Points

1. **In general, quality standards that are applicable to on site work also apply to offsite work unless there is agreement to the contrary.** It is easier to achieve them in factory-controlled conditions though.

2. **Product and factory quality standards and statutory compliance requirements for factories are also applicable.**

3. **Comparability of engineering and product standards.** Procurement of offsite construction can involve production in different countries.

4. **There are many optional standards that may be specified.**

1. In general, quality standards that are applicable to on site work also apply to offsite work unless there is agreement to the contrary.

Construction offsite per se is not covered by any specifically designated legislation and standards. Indeed the Scottish Government has recognised that a future key government incentive to support the growth of the offsite sector in Scotland would be the inclusion of offsite construction within the Section 7 (Sustainability) of the Buildings Standards (Scotland).

Some specialised areas such as pre-cast concrete has established standards but this is not the case for building services.

Building Regulations Approved Document 7 – Materials and Workmanship describes ways of establishing the fitness of materials and the adequacy of workmanship.

2. Product and factory quality standards and statutory compliance requirements for factories are also applicable.

However there are significant standards covering work in manufacturing facilities, the manufacture and operation of products and the safety and quality of buildings during construction, occupancy and use.

Relevant legislation includes, for example:

- The Health and Safety at Work Act 1974 and subsidiary regulations
- The Construction (Design and Management) (CDM) Regulations 2007
- The Construction Products Regulations (see below)
- The Building Regulations 2000 – specifically the Approved Documents
- Factories Act 1961

The Health and Safety at Work Act 1974 places a general duty on employers to consider the safety of employees and others who may be affected by work activities.

It is applicable to the construction phase, subsequent maintenance and operation activities and the safety of future occupants of the building.

The CDM Regulations place a duty on construction project teams to plan a safe method of construction and undertake a risk assessment of the proposed construction works and the safety of the design.

3. Comparability of engineering and product standards.

Procurement of offsite construction can involve production in different countries. The use of international standards may make it easier for overseas companies to quote for work. An example of this could be in the area of structural frames that support services, where Eurocodes are applicable.

The Construction Products Regulation lays down conditions for the placing of construction products on the market by establishing harmonised rules on how the performance of the products will enable the finished works to comply with the building requirements for construction works. Prescribed construction products now have to be CE marked. These rules are generally found in the harmonised European standards for the appropriate construction product. The Construction Products Association has provided guidance on how this is applied to offsite construction in Section 9.

4. There are many optional standards that may be specified. Section 9 provides information on a wider range of standards, many of which are optional but may be specified for a project involving offsite content.

It is worth noting that the RIBA Plans of Work 2013[1], BSRIA Design Framework for Building Services[2] and CIC Scope of Services have been revised in support of the new processes developed for the implementation of Building Information Modelling (BIM) on projects. RIBA, BSRIA and the CIC have revised and aligned their respective plans of work (RIBA Plan of Work 2013, BSRIA BG6/12 and CIC Scope of Services – latest revision still to be published, but referred to in the PAS 1192-2:3013).

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[1] (RIBA, 2013)
[2] (Churcher, 2012)

4.5 Workforce skills

Key Points

1. Both the offsite and onsite workforces need training to equip them with the necessary skills for the use of offsite construction.
2. Skills, expertise and knowledge of offsite construction are required at all levels from site labour to project managers to designers
3. The project team require skills in design for manufacture and assembly, supply chain management and project integration
4. The onsite management and installation workforce need logistical and materials handling skills rather than traditional skill sets.
5. The offsite team require skills in production engineering and process efficiency
6. Post-qualification training of the M&E onsite workforce is needed in new products, methods and time management with the aim of producing multi-skilled workers.
7. There may still be a requirement for a small relatively unskilled work team to focus on the delivery of materials to the point of use.
8. The workforce need to be adequately briefed, informed, and motivated with clear targets, monitoring, and control.
9. In addition to training the workforce, the workplace needs to be appropriate for the tasks required with material delivery and storage, mechanical handling equipment and work area control all addressed.

The key to effective use of offsite construction methods is to be aware of what they are, when they can be used and when in the project process this needs to be considered. As such all the project team need to be aware of these requirements – whether client, architect, designer, project manager or installation team.

As with much of the offsite construction approach, preconstruction planning and preparation is required. Appropriate use of skilled labour and training of the relevant sections of the workforce in the required innovative methods are essential for the successful use of offsite construction methods. Offsite construction requires higher levels of skill and flexibility in the installation workforce than more traditional methods, with greater technical skills needed. In addition to the traditional skills associated with building services installations, the workers will need to cope with the changes in the production process and a greater level of complexity and sophistication in the systems used.

In the manufacturing phase of offsite construction, appropriate skills are needed to match the requirements – as for manufacturing in general. The onsite skill set needed for both management and installation workers is very different to traditional practice as the requirements will include the assembly of ready-made components, the use of new materials and systems, the handling of large building services modules and the need to ensure that sophisticated systems work as they should. This requires skills like logistics, material handling, safe working with heavy components, material and equipment planning, knowledge of new products and methods, time management etc.

New skills needed both offsite and onsite
In addition to the new sets of skills needs for offsite construction in the factory, there are also new skills needed for onsite workers – both for management of the process and for installation, to deal with the assembly of ready-made components, the handling of large building services modules and the use of new materials and systems.

For example rather than "building with sticks" ie an individual worker carrying each required item and tools up and down to the point of use, moving a large building services module (most are over 6m in length) into place, and then connecting it, requires very different skills including knowledge of mechanical handling.

For example preassembled ductwork sections often have pre-gasketed ductwork joints for joining in, yet on site ductwork fitters have been observed applying mastic unnecessarily. Obviously they were not informed of the requirements of these newer products.

Training, briefing and motivating the workforce all need to be addressed. Productivity and quality are clearly linked to attitude and skills. Bonus structures need to be clear. The workforce need to be adequately informed, with clear targets, monitoring, and control. A project culture should be fostered which encourages affiliation to the project, where the team all work together to achieve the desired good end result, and where contribution is recognised.

In addition to training the workforce, the workplace needs to be appropriate for the tasks required with material delivery and storage, mechanical handling equipment and work area control all addressed. Gang/team size and work organisation within gang should also be planned, and the workforce provided with appropriate clothing and equipment – such as overalls and toolbelts.

The UK CES is, at the time of writing, aiming to develop capabilities specifically aimed at the use of offsite construction methods.

Multi-skilling
Site construction needs to be carried out by a relatively small dedicated team of multi-skilled site operatives who typically develop their expertise over a series of projects. Modern building techniques require fewer specialist craftsmen but more workers able to undertake a range of functions based around processes rather than trade skills.

Rethinking Construction 1998 Construction Task Force Report. J Egan

There is a need to shift project preliminary costs and associated skills from the design office and site into the offsite manufacturing element of work. Currently time and cost are often unintentionally "double accounted" in this context.

In the case of design, the initial concept should not be taken too far before getting input from offsite manufacturers. They bring a different skill set and a greater understanding of supply chain capabilities and costs. If the design is taken too far experience has demonstrated that there will be wasted effort.

Skills included in site preliminary costs (or site overheads), whether at the initial, ongoing or final stages of a project, can generally be significantly reduced. Taking work offsite generally reduces the duration of the time spent on site and the need for some specialist skills such as scaffolding erectors and specialist inspectors.

Further reading on workforce skills:
ECITB Securing Engineering Construction Skills for the Future BSRIA TN14/97 Improving M&E Site Productivity

BSRIA TN 13/2002 Site Productivity, 2002

4.6 Assessing offsite suppliers and locations

A key part of deciding to use offsite construction is to find and assess suitable providers and locations for offsite manufacturing and assembly.

The following checklist has been found to be effective in assessing offsite suppliers[3]. An alternative approach would be to rely upon a supplier being registered with the Buildoffsite Registration Scheme run by Lloyds Register. (See section 9).

1	**Design**
	Is there evidence of market research, benchmarking and innovation?
	Is there evidence of ongoing design evolution and product development?
	Is there evidence of compliance testing and management of relevant certification?
	Does the company have in-house design capability?
	Do they have 2D and 3D CAD or BIM capabilities that are adequate to meet project requirements?
	Do they have a good understanding and evidence to support the provision of design for manufacture and assembly solutions?
	Are they capable of providing client teams with design for manufacture and assembly advice on their overall system?
	Is there a good approach to collaboration management?
	Are package interfaces well managed?
	Do they have an R&D / product development strategy?
	Do they have a robust production development process?
	Are design reviews carried out ensuring that the design and development outputs have met the requirements?
	Does the product design comply with standards? Can external test certificates be provided?
	Is the cost for the design, development and prototyping & tooling included within the product pricing?
2	**Their management of their suppliers**
	Is their supplier selection process rigorous?
	Is quality and delivery performance rigorously managed?
	Are opportunities to drive value improvement routinely reviewed?
3	**Production capability**
	Do they have a current state & future state value stream map?
	Is there effective storage of manufactured samples?
	Do they use process Failure Modes and Effects Analysis, testing and analysis?
	Is there quality control of all elements?
	Do they have the ability to handle both large and small orders (storage, resource, quality control etc.)?
	How is the transfer of materials between sites and suppliers managed?
	Is their pre-production planning process robust?
	Is there a formal production control procedure?
	Are their lead times and stock levels actively minimised?
	Are there capacity planning procedures in place and can they meet demand for a complete project?
	table continued overleaf...

[3] It is based upon a checklist used by the former BAA Product & Manufacturing Development Team

4	**Document control**
	Has the organisation implemented controls for the identification, collection, indexing, filing and disposal of records?
	How are obsolete documents controlled? Check that obsolete documents are withdrawn from use.
	Are retention times for records established and recorded?
	Is it possible to identify the current status of documents and parts? Check used forms back to originals.
5	**Manufacturing control**
	Has a Manufacturing Process Map and a Control Plan been prepared to outline the “Key Process steps”?
	Does the Manufacturer utilise processes, machines, fixtures, gauges and test equipment as documented within the Control Pan and Process Maps?
	Have Operator Work Instructions and Standard Operations been specified for the process?
	Are there formal “in-process” quality checks undertaken against the standard documentation? – Is there evidence to support closure of raised issues?
	Is Process Capability measured for critical Processes? is it > 1.33, ie capable?
6	**Facilities**
	Are the facilities suitable for the work to be undertaken?
	Is the equipment suitable for the work to be undertaken?
	Is there a preventative maintenance regime in place?
	Is there a 5S regime or equivalent behavioural change process in place?
7	**Logistics**
	Is there a formal materials receipt process?
	Is the inventory management system mature?
	Are goods suitably protected during manufacture and for dispatch?
	Are transport risks understood & mitigated?
	Are the goods clearly identified upon dispatch?
8	**Maintenance**
	Is there a planned maintenance system that defines maintenance criteria, responsibilities and records to keep?
	Is maintenance conducted at the prescribed frequencies for all equipment?
	Are maintenance records analysed for trends and improvement purposes?
	Are key parts (spares) held as available for key manufacturing equipment?
	Is there any evidence of TPM (Total Preventative Maintenance) being used?
9	**Project management**
	Are their project management resources sufficient to service our requirements?
	Are their project management processes robust?
10	**Continuous improvement**
	Is a Continuous Improvement culture evident within the business? (Outline the main points of this process)
	Is there any evidence to support the use of “Lean Improvement” techniques eg 8 wastes, fast die or tooling change overs, cycle time analysis, line balancing, etc being employed?
	Is there any evidence to support the use of Six Sigma Improvement techniques ?
	Are the business’ KPIs clearly displayed and tracked throughout the workplace, eg process performance including downtime, scrap & reject levels, delivery performance, customer complaints etc.?
	Is there any clear evidence of “process Improvements” being tracked?
	table continued overleaf...

10	Continuous improvement (continued)
	Is there any process in place to quantify and track the financial aspects linked to “process Improvements” ?
	Is the continuous improvement (CI) responsibility clearly defined in the organisation structure?
	Are the benefits from CI activities passed on to the customer in any way?
	Is there a process for capturing improvement ideas from the work force and converting them into results?
11	**Quality**
	Is there evidence of a problem resolution process based on the quality performance data?
	Are control plans / standard operation procedures used?
	Is there a gauging calibration system in place?
	Is there evidence that the supplier uses quality cost data within its management control system?
	Is there evidence to identify appraisal costs i.e. systems, processes or procedures that exist to look for problems – inspection?
	Is there evidence to identify prevention costs i.e. any systems in place to prevent errors occurring?
	Is there evidence to identify internal and external failure costs i.e. the cost associated with defects being created.
	Has the supplier’s quality management system been certified for the required scope under ISO 9001?
12	**Personnel**
	Is there succession planning in place (or is there over reliance on individuals)?
	Are personnel performing tasks qualified on the basis of appropriate education, training and / or experience?
	Have adequate resources been provided to ensure customer satisfaction? (No. of QA / QC staff & support)?
	Who Identifies training needs?
	Has a system been established to manage training and confirming competences?
13	**Health and safety**
	Do they have a good H&S regime with subsequent low accident rates?
	Are they members of an industry recognised H&S assurance scheme?
14	**Environmental**
	Is there clear evidence of an environmental management system being adopted and is it ISO 14001 certified?
	Is there evidence that supports the use of renewable materials?
	Is there any Policy to support the reporting of environmental issues that are relevant to the company and is there evidence available to demonstrate compliance?
	Is there any evidence to support the company engaging with stakeholders, employees, communities, shareholders and campaign groups regarding environmental issues ?
15	**Social issues**
	Wages & benefits – Is a policy in place to ensure that wages and benefits comply to local laws and is there evidence available to demonstrate compliance?
	Hours of work – Is a policy in place to ensure that working hours comply with the limit set by local law and is there evidence available to demonstrate compliance?
	Child labour – Is there a policy in place that ensures only workers over the local legal age limit are employed and is there evidence available to demonstrate compliance?
	Forced labour – Is there a policy in place that ensures use in not made of forced or involuntary labour and is there evidence available to demonstrate compliance?
	table continued overleaf...

15	Social issues (continued)
	Discrimination – Are there policies in place that ensure there is no discrimination in hiring, promoting or employment conditions on any grounds and is there evidence available to demonstrate compliance?
	Representation – Is there a policy in place that allows for worker representation through a legal framework and is there evidence available to demonstrate compliance?
16	**KPIs**
	Is visual management evident?
	Are they measuring on time delivery (in full, in and out)?
	Are there processes in place to make process/specification/buying improvements to meet desired cost improvement targets?
	Are they measuring Overall Activity Effectiveness (or equivalent)?
	Do they monitor quality performance?

In addition to the general aspects covered above, the project will have specific inspection and audit requirements as the project progresses, including and factory based acceptance tests (FATs) of particular equipment assemblies.

The above checklist can also be adapted for the onsite aspects of a project, in particular for the aspects associated with installation and commissioning of the offsite elements.

5.0 Making Offsite Construction Work – by project stage

Making offsite construction work involves good design, rigorous planning, and a knowledge of supply chain capabilities, including a general understanding of production lead times, particularly where bespoke assemblies will be required.

This section is structured around the CIC's project stages, as produced in 2012, and adopted by RIBA in its 2103 Plan of Work. It highlights where and how design for manufacture, assembly, commissioning, maintenance, disassembly and disposal or re-use may be carried out effectively.

CIC		RIBA	
0	Strategy	0	Strategic Definition
1	Brief	1	Preparation & Brief
2	Concept	2	Concept Design
3	Definition	3	Developed Design
4	Design	4	Technical Design
5	Build & Commission	5	Construction
6	Handover & Close Out	6	Handover and Close Out
7	Operation	7	In Use

The CIC column reflects the work done with the UK Government's BIM Task Group. The final stage (7) includes the end of the facility's life.

The methodology described below has been used successfully on a number of projects, including a major airport terminal building and a range of smaller projects. It should be adapted to suit the context in which it is being used.

Each of the following sections list a range of "Tools" which may be applied at that stage of a project. These are described in more detail in chapter 10 below.

5.1 Strategy / Strategic Definition

CIC stage 0 Strategy, RIBA stage 0 Strategic Definition

Key Points

1. Consider the bigger picture. Are there gains to be made by considering the property or project portfolio as a whole or are there benefits that can be gained by applying an offsite strategy to a programme of projects?

2. Standardisation & customisation. What aspects of the client's business would benefit from standardisation and how can this be done in a way which still gives them interesting and stimulating facilities?

1. Consider the bigger picture

At the project portfolio or programme development level (pre-project brief preparation) there is an opportunity to review the overall opportunity for applying design for manufacture, assembly and commissioning to it.

2. Standardisation & customisation

This may identify opportunities to reuse existing "off the shelf" products or get client specific standard products or designs developed. When analysed holistically, most construction sectors have core requirements, which are common across multiple projects. These are accompanied by project specific requirements such as the ground and wind conditions or planning and aesthetic considerations.

Examples where this has been exploited include:

- Circle Health Care's approach to the design and delivery of new hospitals
- The Ministry of Justice's design strategy for prisons
- Heathrow's approach to service level critical plant in airports
- The Education Funding Authority's specifications for new schools
- Anglia Water's programme to standardise water treatment facilities
- The type approval of the major house builders' designs.

The facilities designed for these clients are still interesting, innovative and varied, in part because they have included standardised elements that in turn releases design resources to focus on the aspects that do need designing.

Decisions made at the portfolio or programme level may then be incorporated into the individual project briefs that they cover.

The BAA (Now Heathrow Airport Ltd) offsite strategy for the Terminal 5 Programme was simply stated by setting a target of 65%. Circle Health Care used the 10:80:10 concept with 10% being related to ground conditions, 10% site specific planning and aesthetics, and 80% being standardised, much of which is then produced offsite.

Some major clients are creating their own (BIM) object libraries of standardised elements that they need including in their projects.

Similarly, at the specialist contractor level of the supply chain, the offsite suppliers are also developing their own BIM object libraries for their preferred components that they use to build their customised assemblies, such as plant rooms, vertical risers or horizontal service distribution modules.

Tools

Pictogram	Representing
	The commercial aspects
	BIM & configuration management – development of programme or portfolio wide standard object libraries
	Design for Manufacture – where there is a strategic requirement
	Design for Assembly – where there is a strategic requirement
ERP	Enterprise Resource Planning
6σ	Six Sigma ™ – to determine what represents value to the client

The CIC project stages were developed with the UK BIM Task Group and are being adopted by the professional bodies in the UK construction sector. They are used here as the most generic definitions available.

5.2 Brief / Preparation and Brief

Construction Industry Council (CIC) project stage 1, Brief, output: to deliver Project Brief and Procurement Strategy[17].

Equivalent to RIBA Plan of Work 2013[18] stage 1 Preparation & Brief.

Key Points

1. **Know your client.** At brief development stage, the client is unlikely to specify how a project is to be constructed. However this may not be the case for serial clients who have in house design standards.

2. **Keep an open mind and keep your options open.** Being very prescriptive at this stage can rule out the option to use offsite solutions.

3. **Keep budget and cash flow planning flexible** to accommodate alternative procurement routes, including offsite options.

4. **Align payment triggers for work in progress with the due dates of deliverables.**

5. **Allow sufficient time to consider design options.**

6. **Use collaborative approaches to procurement.** Involving potential team members including suppliers of offsite construction assemblies from the start allows offsite opportunities to be explored and considered at the appropriate project stages.

7. **Look at past exemplars.** Where and how have offsite solutions been used for the construction of similar facilities in the past? What were the outcomes?

8. **Look ahead to the project requirements.** Both offsite assembly and offsite manufactured modules need to be integrated with more traditionally constructed in site elements. This requires:

   a. **The management of interfaces** between the different work packages

   b. **A structured approach** to the analysis, design, integration, test and acceptance of the systems

   These tasks should be included in the brief to ensure they are adequately addressed.

9. **Utilise expertise from BESA and Buildoffsite** to help explore options.

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[17] Source for CIC project stages: BIM Task Group Report 104 Plan of Work – Industry Framework for the Refinement of Information on Construction Projects in the Built Environment
[18] RIBA Plan of Work 2013 Overview ISBN 978 1 85946 519 6 can be obtained at: http://www.architecture.com/TheRIBA/AboutUs/Professionalsupport/RIBAOutlinePlanofWork2013.aspx#.Uax2D5XIYnU

1. Know your client.

Most ‘one-off’ clients are looking for the performance of the end product, (ie a comfortable and productive enclosure in which to make widgets), not how it gets there.

However repeat clients will have a very different outlook. For example some supermarket and fast food outlet chains that develop serial projects will often have a standard design approach and solution already mapped out. Arguments for change will need to be robust and raised at the very beginning.

2. Keep an open mind and keep your options open.

Being very prescriptive at this stage can rule out the option to use offsite solutions.

In the first instance the client may be appointing one or more planning and / or design consultants.

Their brief should focus upon:

- What the client organisation’s needs are of the new facility (including definition of location, functions, operation, carbon use, and quality)
- Project performance requirements (including costs, time, health and safety, use of standard designs, its design for manufacturing, assembly, commissioning and end of facilities’ life strategy, special construction requirements)
- Constraints or opportunities associated with its operations that are relevant to the project (including learning from earlier projects and benchmarking)
- Project governance and information and model management (BIM)

The design deliverables to the client should consider the CIC guidance and not be too detailed at this stage.

3. Keep budget and cash flow planning flexible

The budget and cash flow planning should be sufficiently flexible to accommodate alternative procurement routes, including offsite options. These may require a different payment schedule to traditional construction, for example perhaps involving a deposit to reserve factory capacity or the need for a stage payment when materials are to be purchased by the factory.

4. Align payment triggers for work in progress with the due dates of deliverables

Avoid encouraging early delivery of products ahead of schedule or out of sequence. It may lead to delays due to the overall construction plan becoming constrained due to congestion of the site and the need to shuffle materials around. Pay for the correct delivery of the right quality items at the planned time.

5. Allow sufficient time to consider design options

It is important to allow sufficient time in the overall plan to consider a range of design options. Avoid rushing into detail, which can also result in assumptions being made which may turn out to be inappropriate or undesirably limit design options. For example, a detailed design for a building’s services may pre-determine the construction sequence or at least limit the scope for preassembly. The creation of a vertical riser in a frame rising through multiple floors may be more efficient than having a smaller assembly for each floor or for fitting components in a traditional manner in situ. However, lifting restrictions on the site may prevent this option from being used. Similarly, if there are already systems available for constructing such a building, these supply chains may be excluded if the design contains too much detail prior to tendering. Allow sufficient time to compile a holistic view of the project.

6. Use collaborative approaches to procurement.

Most suppliers of offsite construction assemblies prefer a collaborative rather than transactional approach to procurement. If they can be involved from the earliest project stages, this allows them to submit ideas and advice to designers, and provide the expertise on the use of offsite components and assemblies that the designers may lack.

The example on the right shows the upper part of a partition wall delivered as part of a services distribution module for a hospital corridor. The wall penetrations have been created and sealed in the factory, greatly facilitating the erection of the in situ wall sections. (Image courtesy of NG Bailey).

To encourage collaborative behaviour, it is worth considering “single (or integrated) project insurance” which is likely to encourage working together to find the optimal solution to an issue rather than each company trying to optimise its own position. With a single insurance policy for the project risks, the claim would not be on the individual supplier. Once people realise this they do not need to be defensive for financial reasons.

On a recent major UK project this, combined with a shared risk and reward fund, resulted in it being in everyone’s interest to minimise the impact on the fund. When a major issue arose, the out-turn cost of it was substantially reduced through the collaborative development of a solution. This benefited both the client and the companies sharing in the fund at the end of the project.

7. Look at past exemplars.

At this project stage you need to consider the feasibility and potential scope of including offsite elements into the concepts that will be explored at the next stage. For this is it very helpful to look at how similar facilities have been constructed in the past.

For example, data centres, plant rooms, pumping stations, educational and pre-school facilities, hospitals and laboratories have all been constructed offsite with significant building and engineering services content. Many large facilities have also been developed as hybrid projects with a traditionally constructed structure containing extensive use of modularised and unitised assemblies of services equipment.

The case studies in Section 6 provide some examples.

Find out if there are system build options available for your type of facility. There are for a wide range of projects, including schools, laboratories, operating theatres, car parks and water treatment and pumping stations, to name a few. For example Buildoffsite provide a specifiers guide to system build car parks.
http://www.buildoffsite.co.uk/pdf/digest_X495_v3.pdf

8. Look ahead to the project requirements.

Where projects involve both offsite assembly and offsite manufactured modules these will need to be integrated with more traditionally constructed on site elements.

This requires two critical tasks which shall be included in the brief to ensure they are adequately addressed :-

a. The management of interfaces between the different work packages

b. A structured approach to the analysis, design, integration, test and acceptance of the systems. For example one such approach is illustrated in figure 5.1.

c. The project starts at the top left, with "requirements analysis" and concludes in the top right with "system acceptance".

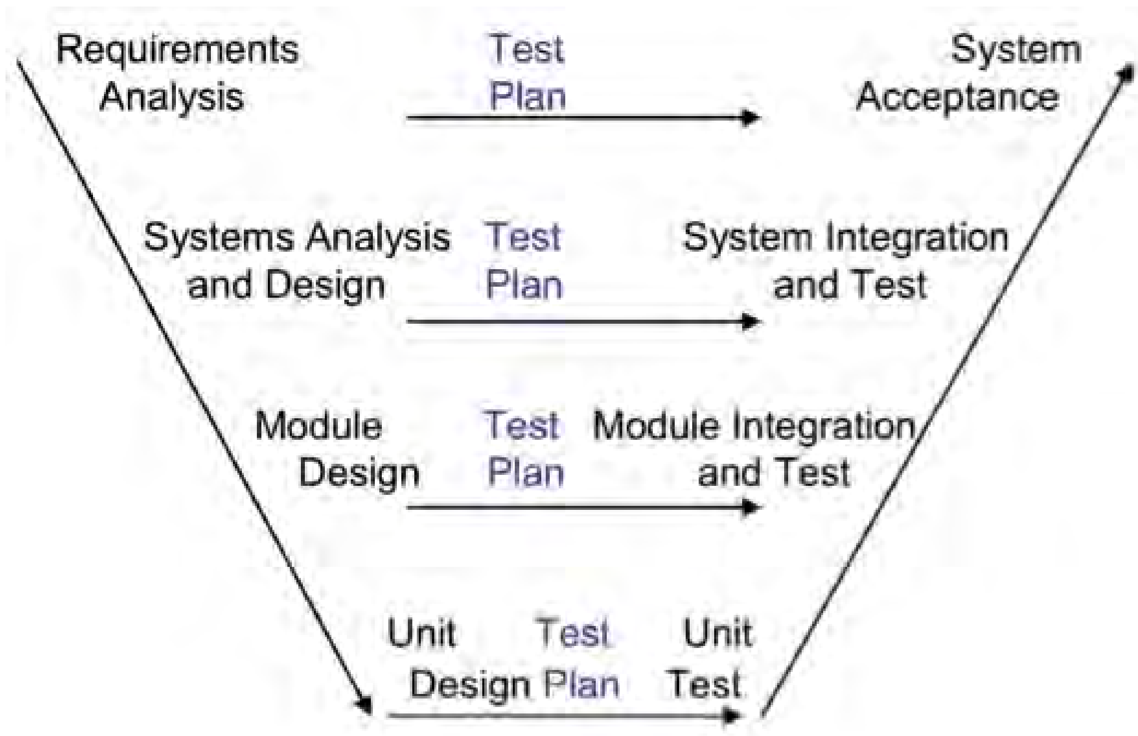

Fig. 5.1 From requirements analysis to system acceptance

(Note: This approach draws on the experience of systems engineers in the construction sector and also in other sectors).

The use of BIM on the project (following the process described in BS PAS 1192-2) (http://shop.bsigroup.com/Navigate-by/PAS/PAS-1192-22013/) will contribute significantly to managing the work package interfaces. For example, Sections 5 and 6 cover information delivery assessment of needs and procurement. Section 7.6 provides guidance on how defining volumes within tunnels (PAS figure 11) or a building (figure 12) can be used for special coordination of services etc. The PAS also defines how information can be shared by a project team in a common data environment.

9. Utilise expertise from BESA and Buildoffsite

Use this to help explore options, for example information on previous projects covering hospitals, schools, airports and many other contexts are available, together with the option of possible visit opportunities.

The relevant information from BESA can be found here: http://www.theBESA.com/
The relevant information from Buildoffsite can be found here: http://www.buildoffsite.org/

Tools that should be considered at this stage

Pictogram	Representing
	Benefits assessment
	The commercial aspects
	BIM & configuration management – development of programme or portfolio wide standard object libraries
	**Design for Manufacture** – where there is a strategic requirement
	**Design for Assembly** – where there is a strategic requirement
ERP	Enterprise Resource Planning
6σ	Six Sigma ™ – to determine what represents value to the client

5.3 Concept / Concept Design

Construction Industry Council (CIC) project stage 2, Concept, output: to deliver Refined Project Brief and Concept Approval[19].

Equivalent to RIBA Plan of Work 2013[20] stage 2 Concept Design.

Key Points

1. **Focus on decisions that need to be made early and information needed for them.** The new Plans of Work are based upon answering questions for the client.
2. **Consider options, both on and offsite.** Whilst determining the services strategy for the project, there will inevitably be a range of ways of delivering the chosen option. Most projects could involve varying degrees of offsite construction.
3. **Look for big wins.** This is the stage where innovative thinking can really pay off.
4. **Avoid getting into too much detail.** It is easy to make decisions that unintentionally limit offsite supply chains to respond to tender invitations later. The degree of information certainty at this stage may only be within the range of 75 to 80%.[21] The key here is to "outline" the design.
5. **Aim for a Lean way of delivering the project.** Apply the principles of Lean Construction.
6. **Consider Logistics**. Logistics can have significant impacts on developing the concept design and modularisation including their size, weight and composition.
7. **Concept Design for Services Modules.** The approach to design varies little in essence and uses the same skill sets and tools, there are however some nuances to making the best of the approach

1. Focus on decisions that need to be made early and information needed for them.

This stage involves "site selection", understanding "site constraints" and "setting scope, scale, form and primary design criteria". The spatial arrangements, structural philosophy and technical studies at this stage shall influence the range of build approaches available.

2. Consider options, both on and offsite.

These will be compared in terms of performance, including measurable aspects relating to the "client's drivers" (discussed in Section 3.1), the ability to deliver the project safely, for an affordable cost and acceptable construction programme. Feedback from previous projects will be considered. The IMMPREST tool, (described in Section 3.6) may be used for this.

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[19] Source for CIC project stages: BIM Task Group Report 104 Plan of Work – Industry Framework for the Refinement of Information on Construction Projects in the Built Environment
[20] RIBA Plan of Work 2013 Overview ISBN 978 1 85946 519 6
[21] Source for CIC project stages: BIM Task Group Report 104 Plan of Work – Industry Framework for the Refinement of Information on Construction Projects in the Built Environment

3. Look for big wins.

It is hard to predict what these might be. Here are a few examples.

- Reduce the number of people and materials deliveries required to get through security checks. An airport operator aimed to take 80% of the mechanical and electrical labour offsite as security checks were taking up to 2 hours at peak start times.
- On a very large or complex project, look at how to avoid local labour supply or skills limitations and inflationary pressures by spreading the work across a wider geographical area or using different skill sets.
- A pharmaceutical company set itself the target of building a manufacturing facility in 13-weeks so as to maximise the exploitable period of its product's patent.
- A major client rented a temporary factory to carry out final assembly near to the site so as to avoid transporting large modules and a lot of empty space over long distances.
- A city centre client had no available space for storage so just in time logistics and large preassembled modules via an offsite logistics centre meant construction was not dependant on onsite facilities and guaranteed workflows met programme.
- Consider conceptually how to integrate building services with alternative structural and architectural solutions, including panelised systems such as pre-cast concrete and structural integrated panels (SIPs) and where these are brought together. Some pre-cast prison cells have been delivered with services pre-installed at the casting facility.
- Think about avoiding the need for scaffolding, temporary protective facilities or how to minimise temporary works during the installation of services. Including access gridding at works within service risers for example saved one project £120k in temporary access scaffolding to risers.
- Having a flat soffit makes the installation of services a lot easier and faster leaving a far more flexible structure for end users to modify in future.
- Different crane use options or limitations may drive solutions that offer more value. Including hook capacity considerations in conjunction with the fabric and structure could reduce lifts by significant amounts as larger and heavier sections can be utilised. By this approach risers can be installed typically 3 floors high at once, reducing lifts by 2/3.
- Look to alleviate site constraints such as ingress and egress. The Olympic Delivery Authority used the adjacent waterways around the Stratford site which was essentially landlocked by rail road and rivers as a key logistics route with capacity for large weights and dimensions. (http://learninglegacy.independent.gov.uk/documents/pdfs/sustainability/149-transport-of-construction-materials-sust.pdf)

Some of the above may seem detailed; however, thinking about them can lead to conceptual breakthroughs. Avoiding the need to scaffold 4 airport piers so they could continue to operate whilst a corridor was assembled on top of them saved the client (BAA) £12m in lost income!

4. Avoid getting into too much detail.

The undesirable tendency to take a design to a greater level of detail than is really required is to be avoided. The objective is to develop an outline design that documents the "sustainability, maintenance and Operational Strategies and Handover Strategies" (RIBA 2)

Figure 5.2

122 Leadenhall Street, informally known as "The Cheese Grater" is a case in point. Prior to the award of the construction contract, a structural design was developed which was later replaced with an alternative ("non-compliant") approach put forward by the winning contractor. The photograph shows construction in progress in late 2012. The "non-compliant" design enabled the contractor to exploit advanced pre-cast concrete and services preassembly supply chains that it had developed

Image copyright West One Management Consulting Ltd

5. Aim for a Lean way of delivering the project.

The winning contractor for the Cheese Grater is an extensive user of BIM and 3D scanning tools. The photographs below indicate that other factors above have also been considered in the design process.

Figure 5.3

A module prior to being lifted into position

The delivery logistics exploit the atrium space to overcome site constraints, enabling a regular delivery flow across the site, and uses adapted trailers that accommodate the large volumetric modules.

Note also that safety fences are added at ground level to modules, which already integrate structure and services, before they are lifted into their final position.

Image copyright West One Management Consulting Ltd

Figure 5.4

An adapted transport trailer increases height and width of module carried.

Note that a key aspect of the logistics plan will be the lifting strategy. In this example, the capacity of the cranes that have been positioned at the top of the building will have been critical to making the whole concept work.

The preassembled services can be tested at the factory prior to dispatch to reduce the amount of onsite commissioning.

At this stage just get the overall principles defined.

As a building progresses, each floor or bay receives the cladding system and becomes weather tight. As zones used within the building services strategies become weather tight and plant is installed, they can be isolated and opportunities open up for pre-commissioning of sub-systems by zone. At this early stage, it is possible to establish a strategy for commissioning that may help reduce the overall project duration, for example by each module or group of modules being pre-commissioned and tested at works or being inherently self balancing.

The 122 Leadenhall Street example illustrates the importance of the overall concept and how the unavoidable onsite aspects can be seamlessly combined with a high proportion of offsite elements.

At this level of detail, it is advantageous to aim to optimise the whole building rather than just focus upon the building and engineering services.

Ideally the concept design should encompass such options. The objective should be to avoid the waste created by over design at too early a stage.

6. Consider Logistics

Logistics can have significant impacts on developing the concept design and modularisation including their size weight and composition. Early advice from a specialist will identify key issues and assist in developing the concept. As the design progresses specialist software such as Autoturn can be used with the BIM model of the site to confirm key areas such as swept paths and logistics software to determine delivery programmes etc.

Consider the maximum module sizes and number of services linked with practical constraints for the particular project. In practice module sizes and compositions are determined by a range of factors including the following;

- Transport
- Site constraints
- Construction Programme
- Craneage and lifting capacity
- Manufacturing constraints
- Component Supply

Typical sizes are given for each major module type in the glossary. (Section 7)

6a Transport

Transport costs can account for between 5 and 10% of the value of modules and therefore making cost effective use of the correct type of vehicle can impact on the overall project cost and the carbon emissions associated with wasted capacity. The maximum dimensions of a low loader cab and trailer which can be travel on UK roads without special order from DfT but with attendant and police notification are;

- Height 4.93m
- Length 27.4m
- Width 5m
- Weight 42 Tonne

In practice typical modules would be limited to 3.5m x 3.5m x 18m x 25tonnes to avoid police notification and an attendant when the weight and dimensions of the cab and trailer are taken into account. One example of a company's internal guidance is presented below.

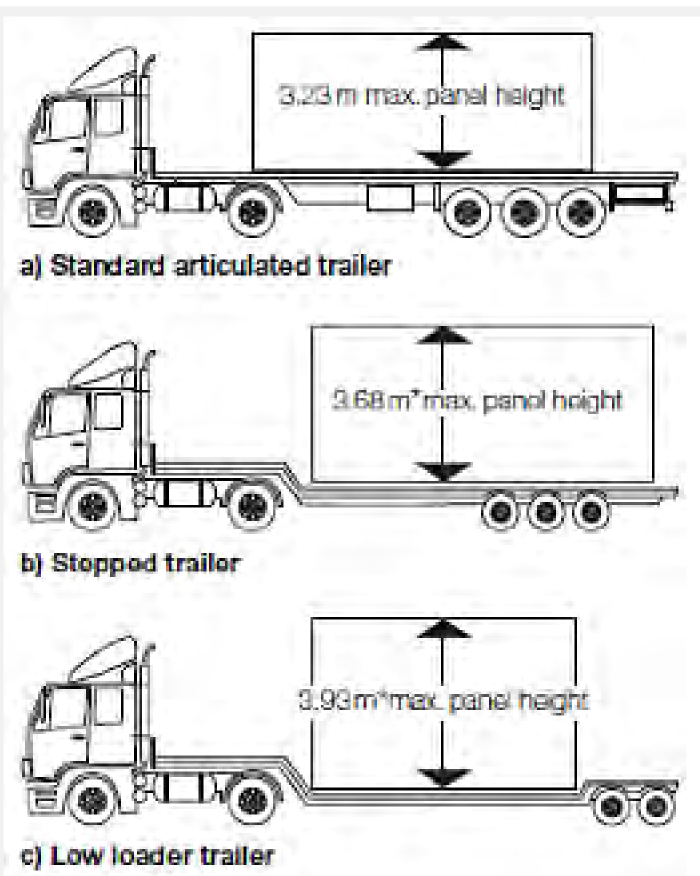


Figure 5.5

Up to date information may be found in the annual Road Haulage Association's Haulage Manual. Refer to:

http://www.rha.uk.net/information/publications/haulage_manual_2010/about_the_haulage_manual

Source: Laing O'Rourke.

6b Craneage and Lifting

Considering the craneage and lifting strategies at this point in the design will determine a number of other aspects such as overall dimensions, weights, material specification, servicing strategy and what combination of service, architecture and structure make sense. Craneage and lifting is a specialist area and as such early advice should be sought. The type and capacity of cranes and other lifting devices will vary through the project programme and be affected by site constraints, in particular access and oversailing of adjacent properties.

Types usually considered are;

- Cranes, Mobile, Tower, Crawler
- Forklifts * Lifting trucks such as Hiab
- Patent lifting devices such as Genie lift
- Strand jacks

Integrating services modules into the main construction programme to take advantage of tower cranes increased site coverage and capacity. This will increase the hook time capacity required and possibly the hook length to allow multi-storey riser modules. Loading of floor modules during construction requires consideration of weathering, material choice and temporary slab load capacity. Keep risers open at the top to allow service modules to be dropped in. Consider using removable roof cassettes or cladding for the later installation of plant or escalators.

Use of roof plant rooms are usually completed after tower cranes have been removed and can use mobile or crawler cranes. Check load bearing capacity of ground, and note that coverage, reach and capacity is reduced so location of plantrooms will be affected. A landing zone and route across the roof may need to be designated and designed into the structure.

Forklifts, lifting trucks and the like are more suitable for smaller modules or side loading through semi completed facades. Consider column spacing to allow 6-7.5m long module use and how the opening in the façade is to be maintained and then completed subsequently.

Lifting devices such as Genie lifts are available from many plant hire companies and range in capacity but only suitable for the smallest module lifting over a single story. A 7.5m module would typically use 2 whilst a fan coil module one. Consider access and sequencing with internal walls and partitions.

Strand jacks have been used where height restrictions limit the use of tower cranes, eg on an airport.

Other devices such as skates for horizontal movement across floor slabs are often used but generally straight lifts are both safer and more effective. Double or triple handling increases the risk of damage and accidents.

Often temporary lifting beams or Assembly, Transport and Installation Frames (ATIFs) are utilised and must be rated for the load intended. Care should be taken with uneven loading or use of straps. Where possible lifting points should be included in the detail design and be simple, fail safe and minimise working at height during the installation.

6c Site Constraints

Mostly these fall into the obvious category, such as programme dates for a good site access suitable for low loaders, turning circles, radii for large vehicles. Laydown for modules not immediately craned into position and parking space for deliveries awaiting crane time. Less obvious might be overhead wires, cavities in made up ground in city centres, adjacent uses such as railways, or time constrained deliveries for which road closures or permits may be required.

A site visit will often determine many of these constraints.

6d Manufacturing constraints

Each assembler and manufacturer will have their own particular constraints; the best way to determine these is to ask! They might be certain sizes they can get though a loading bay door to the capacity of a particular machine.

6e Construction Programme

The best approach is often to combine elements together. This means, however, that the services design and procurement programme must be hand in glove with the structure and architecture. Structural and façade elements can often be very heavy so need to be considered in the round along with service modules and may limit the choices. For example, casting in details such as fixings may be determined at an early point. Whilst they add a small cost at the factory, it is wise to include more rather than omit due to the design being insufficiently developed, always providing that production tolerances are understood.

Ensure openings are left if services modules are to be installed post structural and façade completion.

6f Component Supply

Key components may have programme lead times which are incompatible with design for offsite of wider multi service modules. Early advice and decisions on supply chain will mitigate this. Component supply should form part of an early assessment and be part of preconstruction programming. With increasing globalisation of supply chains some modules or components will be sourced overseas. This should be considered as part of the mix as shipping may add 6 -12 weeks depending on location.

7. Concept Design for Services Modules

The approach to design varies little in essence and uses the same skill sets and tools, however there are some nuances to making the best of the approach.

- Agree key protocols which will be implemented for BIM including CAD, calculation, referencing and other tools which will be passed down through the design, manufacture, installation and FM teams.
- Agree key strategies for plant location, distribution and room and test each against the building fabric and structure. This will need to be a collaborative approach; some key pointers are highlighted in the text but will vary project to project.
- Consider any design issues in later stages which may impact on the strategy.

- Consider how the various areas will be broken down and reflect these in the overall design strategies, for example including 2 smaller air handling units may allow them to be included in modular plantrooms without bridging a break rather than built in situ. Look at room arrangements and how they impact on potential modularisation, ie including a column in the corner of a toilet may make sense in terms of the dry lining but prevents complete toilet pod construction. Linking the breakdown to electrical distribution for power and lighting will also allow increased use of busbar solutions.

- Servicing strategy must be considered holistically, one large riser and horizontal floor distribution can increase overall building height whereas lots of vertical modules can reduce the Gross Internal Floor Area (GIFA). A balance is what is required across all disciplines taking into account any limiting factors, for example maximum façade panel height by the manufacturer, the need for sprinklers in deeper ceiling voids, or a minimum GIFA for investment decision. Each project will have its own drivers, however common themes emerge – accommodation such as prisons and hotels lend themselves to vertical led distribution, industrial and low rise are more horizontal distribution whilst commercial and healthcare tend to fall in the middle.

- Try to avoid roof plantrooms which just follow the building perimeter to prevent shipping empty boxes of air. Often discrete plantrooms can be more cost effective and save significant sums. Use of a louvre to link the plantrooms can give the same architectural feel without the associated on cost.

- Roof plant rooms offer good opportunities for cladding in a different finish to the main system. Consider a lightweight insulated composite to alleviate craneage capacity.

- Identify any dependencies on the programme and how this will impact on riser modules. For example a single floor module can be installed after the structure but only smaller sizes can be easily handled, whereas a multi floor riser can be self supporting independent of the structure and can be lifted in before or after the openings are formed by slab construction. A multi floor riser can also provide integral part of the structure and must be in position before slab construction in which case the detailing needs to be agreed.

- Aim to get the building as watertight as possible as early as possible. Modules are usually fully finished on delivery and so not suitable for exposed or semi completed facades. This is usually a programming issue and should be factored in to the main contract programme, for example including complete façade panels with windows preinstalled.

- Consider maximum module sizes and how they will be moved through the site and building during installation. Consider whether dedicated access points are required in facades, programme changes to internal partitions and weathertightness of risers. Don't be afraid to challenge aspects such as structural design to allow the services to be more effectively installed. Look at column spacings to allow access, avoiding downstand and castellated beams on floors, windbracing on plantroom and riser exit points and columns impinging on horizontal distribution routes. Is the slab and façade construction optimum for services? A flat slab typically provides the best solution.

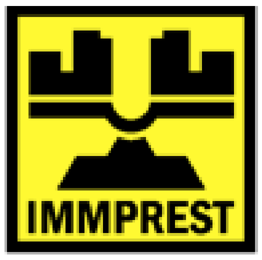
- Distribution in a design intent tends usually to be from point to point by the shortest route for each individual service. For efficient modularisation group together where possible on common frames and select a logical common route. Typically this route will follow circulation corridors and form spines.

- Identical modules are the simplest approach however they may add cost. Often a handed option allows sufficient flexibility whilst retaining sufficient repeatability to keep costs in check. Don't be surprised if all the modules are not identical, there will always be some unique elements; the trick is to limit the number of these and use a flexible manufacturing approach to deal with the differences. Different suppliers take varying approaches to this flexibility and this is a key area to understand. With cellular spaces consider handing them with back to back service riser, whilst looking at notional modules in open plan areas should consider likely terminal unit modules.
- Maximise the use of any module frame by including as many services and other elements as possible such as dry lining, access flooring and the like and ensure the cost plan allocation reflects the intended delivery. Where possible consider combining structure and services modules in one as in the 122 Leadenhall example, this reduces the cost of module support frames. Are module frames required at all or can an ATIF or skinny module approach be use? This is most effectively used for final or secondary distribution where equipment sizes are smaller.
- Connection details may impact on space planning at this stage, for example plug in connectors on distribution boards require additional head room above, medical gas pipework usually requires brazed connections which must therefore be accessible once a module is installed, crimped pipe fittings require access for a hydraulic crimper and cold insulated services require a taped continuous vapour barrier.
- Refurbishment projects do not preclude this approach however modules are likely to be smaller as they will need manoeuvring through existing structures. At a basic level even pre-manufacturing small sub assemblies such as valve sets and support bracketry can have significant benefits.
- Laser surveys of existing (and new) buildings can help with accurate information for design development but need programming in at this point.
- Identify any system differences which might impact on the design strategies ie modular wiring is supported continuously using basket containment which requires additional riser space over single cables. Similarly identify constraints in the system types selected, whether these are modular or otherwise, which may have an impact on the design.

The mix of sub assembly, manufacture component and specialist assembly can seem a minefield on first inspection however they can be approached in a hierarchical manner.

1. Consumables ie Proprietary supports, typically left to assembler or contractor as long as they comply with BS/EN standards
2. Packaged Plant ie Pressurisation Units, typically a range is specified “or equal” by the designer
3. Catalogue sub assemblies Ie Valve Sets, often left to the contractor in a traditional approach but should be specified “or equal” by the designer
4. Specialist volumetric ie Toilet pods – a key component which should be pre-tendered and specified “or equal” by designers
5. Bespoke Modules – can be delivered by a range of assembly providers sometimes in-house within building engineering services contractors and increasingly as a standalone specialist so should be pre-tendered and specified “or equal” by designers.

Tools that should be considered at this stage

Pictogram	Representing
	Benefits assessment (TM Loughborough University)
	The commercial aspects
	BIM & configuration management – development of programme or portfolio wide standard object libraries
LEAN	**Lean Construction Methods**
	**Design for Manufacture**
	Design for logistics
	Design to be modular
	Use common parts and materials
	**Design for Assembly**
	Minimise and manage interfaces
	Design for commissioning
ERP	Enterprise Resource Planning
6σ	Six Sigma ™ – Motorola

5.4 Definition / Technical Design

CIC project Definition, stage output: to deliver approval of coordinated developed design based on graphic and technical information demonstrating how brief is achieved. RIBA Stage 3: Developed Design. **This is the stage in which the RIBA Plan of Work includes "Undertake 3rd party consultations as required and conclude research and development aspects".**

Key Points

1. **Research the market.** If you are a manufacturer, consider how information may be made available to designers.
2. **Start to define interfaces.** In particular between onsite and offsite elements.
3. **Complete research and development.**
4. **Focus on performance.** Requirements should not exclude offsite options.
5. **Define packages** that can be delivered in multiple ways, including using offsite elements.
6. **Determine the benchmark construction methodology.** Select the optimum mix of on and offsite elements for benchmarking future tender returns.
7. **Concept Design for Services Modules.** Developed design phase for services involves most of the same process as normal however there are a number of areas which follow a different timeline so need consideration earlier than traditionally as well as some practical issues to consider.
8. **Complete the developed design.**

1. Research the market

The designer should either have or develop a good understanding of what products, systems and supplier capabilities exist. Manufacturers need to ensure that information about their offerings is easy to find and use. For large projects with published timetables and known design teams, pro-active engagement starts here.

2. Start to define interfaces.

This can be approached in a number of ways. Defining inputs and outputs, touch points and dimensional tolerances all need to be considered. Zones can be allocated for systems and services, air or people to pass through; and ways of isolating noise and vibration passing between areas considered. Particular attention is needed for interfaces between onsite and offsite elements and their associated dimensional tolerances. Configuration management of these interfaces is needed from the start. If something subsequently needs to be changed, its relationships with other things (configuration items) needs to be clearly understood and acted upon if the change is made.

3. Complete research and development

Pure research may need to be well underway even before this stage is reached. However, there is scope for carrying out applied research at this stage, considering the following questions:

- What systems, assemblies, plant rooms etc have been developed?
- How might they be modified?
- Would they be fit for purpose?
- What testing would be needed to validate this?
- Do the test results confirm that the proposed approach is feasible?
- Are further tests or development needed? How would these be carried out, and by whom?

4. Focus on performance

At this stage of a project, aim to keep specific product references limited to those that are defined by the client for strategic purposes. Requirements that are performance based are less likely to inadvertently exclude offsite options.

5. Define work packages

Define work packages that can be delivered in multiple ways, including using offsite elements. Incorporate the interface definitions mentioned above. Extend configuration management to the package definitions. Define the facility in terms of form and function but give potential suppliers scope to determine how they could meet the brief.

6. Determine the benchmark lean construction methodology

Select the optimum mix of on and offsite elements. This needs to be done in a holistic way so that the interaction of options is understood. Putting heavy plant in the basement or on the ground floor could result in a lower performance requirement of the super structure or roof. Selecting a building envelope that can be modularised and installed in a manner that brings forward the time that building systems can be commissioned may reduce the overall programme duration. Consider the client drivers (in section 3.1) and identify ways of delivering increased value. Then use the results to create performance benchmarks for the project.

7. Developed Design for Services Modules

The developed design phase for services involves most of the same processes as normal; however, there are a number of areas which follow a different timeline so need consideration earlier than would be traditional. There are also some practical issues to consider.

- The agreed offsite strategies should be developed during this phase and should start to incorporate advice from specialist and contractors.

  Modules impose loads on structure differently than site assembled service installations. As module content and detail is developed ensure that the structure incorporates fixing points, eg Halfen channel inserts, can take point loads both in final position and moving into position. Consider base design for skid mounted assemblies and plantrooms to spread the load evenly. Consider imposed point loads and numbers of fixings required for suspended modules as the cost of upgrading capacities of slabs can be significant. Factor in additional loads for steel frame when advising the structural engineer of loadings. Expansion and contraction arrangements with modules may be differently imposed on the structure due to module frames and these should be detailed at this stage.

- Programme implications related to multiservice modules with additional elements or serviced walls, for example, mean that design for the building engineering services may need to be further advanced than traditionally. The need to incorporate fixings or elements within earlier delivered packages, such as structure, means that this needs to be carefully aligned across all design disciplines. The lead designer should have experience in this respect and the main or specialist contractor may be able to assist with detail programme dependencies.

- Where services are incorporated into other elements, ie a serviced wall, the services design should be sufficiently advanced to allow this or the strategy set out in the concept stage to make the design independent for these elements.

- Carry out calculations in a manner, which assumes a modular approach, ie for cable sizing assume a radial rather than ring circuit, systems grouped and routed according to the concept strategy.

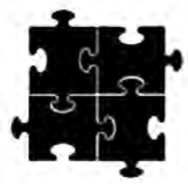
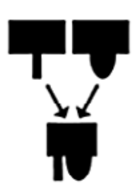
- Developed design will incorporate field connections and equipment such as electrical MDB connectors or controls outstations; these should be mounted on distribution or terminal modules within the factory. Actual lengths for pipes, ducts and wire should be incorporated in calculations as point-to-point calculations often under estimates.
- Each proprietary system selected will have certain constrains and these should be identified and included in the developed design.
- Structural analysis of modules should be sufficient to confirm the worst case for each family of module used and may be generic from project to project, conforming to Eurocode design standards.

8. Complete the developed design

Document the design, preferably in the form of a BIM model and supporting referenced information.

Tools that should be considered at this project stage

Pictogram	Representing
	Benefits assessment (TM Loughborough University)
	The commercial aspects
	BIM & configuration management – development of programme or portfolio wide standard object libraries
LEAN	**Lean Construction Methods**
	**Design for Manufacture**
	Design for productivity
	Design for logistics

	Design to be modular
	Design to make manufacture easy
	Optimise design for suppliers' capabilities
	Use common parts and materials
	**Design for Assembly**
	Minimise and manage interfaces
	Simplify and reduce sub-assemblies and component parts
	Reduce assembly risks
	Make sub-assembly easy
	Design for easy handling
	Use efficient methods of jointing
	Prototyping and first-run studies

	Design for commissioning
	Design for maintenance and decommissioning
MRP	Materials (or Manufacturing) Requirements Planning – for prototyping and 1st run studies
ERP	Enterprise Resource Planning
6σ	Six Sigma ™ – Motorola

(Further details on how to apply these are provided in Section 10 Tools).

By the end of this project stage, there will be the basis for integrated production information to be produced on a package basis with limited risk of changes to primary co-ordination.

There should be a benchmark lean construction methodology optimised with respect to on and offsite activities. In most cases this will be a hybrid of the two.

The project is also likely to have a BIM library containing client specific designs and standard products along with generic representations of the building services and systems.

5.5 Design / Technical Design

CIC project stage 4 Design output: to deliver integrated production information; specific component design and specification based on graphic and technical information demonstrating how brief is achieved.

RIBA Stage 4: Technical Design

This is the stage in which the RIBA Plan of Work includes "all architectural, structural and building services information, specialist subcontractor design and specifications".

Key Points

1. **Tolerances**. Understand supply chain capabilities and what is achievable onsite.
2. **Manufactured elements & differing supply chains.** Keep components non-proprietary where possible.
3. **Modelling.** Use 3D BIM to coordinate designs and simulate system performance.
4. **Fixings to structures**. Different structural systems have different dimensional characteristics and production sequences, which influence what fixings can be pre-positioned.
5. **Design freeze.** Work offsite will probably run ahead of work onsite so a formal design freeze before manufacture starts is needed to avoid costly rework.
6. **Standards & Approvals.** Be clear on what the applicable standards are and how approvals will be obtained, particularly for innovations.
7. **Programmes.** Construction programmes with a high offsite content can be a lot shorter than traditional methods, even allowing for the factory production lead time.
8. **Methods statements.** Factory methods statements are typically broken down into simple single point lessons, a format which is very visual and can also be used effectively for site work.

This stage involves the specialist production drawings taking the consultant design to a point suitable for manufacture offsite. This raises issues as traditional onsite methodologies allow skilled artisan operatives to make minor adjustments to suit site conditions, whereas this is not possible in a factory environment.

The level of detail required will be greater to compensate for this but will have a real benefit of a fully worked through design. At this stage final framing, commodity components manufacturer specific equipment detailing, manufacturing information such as break jointing is finally resolved. Few if any coordination issues arise at this point.

1. Tolerances

Designers of offsite systems need to understand site build tolerances in proposing solutions. It is easier to achieve tighter production tolerances in a controlled factory environment than on a construction site. Machine tools, jigs, fixtures and metrology equipment all contribute to this. Designers who understand what is easily achievable without incurring additional cost can exploit this to achieve:

- Higher performance eg air tight joints
- Faster assembly and shorter programmes as parts fit first time
- Less waste and rework
- Simpler setting out onsite.

Different product families, materials and production methods have different dimensional tolerance characteristics. These need to be understood in order to exploit them.

2. Manufactured elements & differing supply chains

Most offsite construction constitutes the assembly of "off the shelf" products and materials that are sold by the linear metre and cut to the required length. Sometimes these can be purchased directly from the manufacturer others will be procured through distributors. Such items can be categorised into "runners", "repeaters" or "strangers" and each will be treated in a different way.

Runners could include low value components, such as fixings and standard brackets which are manufactured or used frequently. They may be supplied by a local company, which replenishes stores next to the assembly line on a regular basis (say weekly), probably using a "2 bin system". When the bin closest to the operative is empty it is moved to the back of the rack and a full one pulled forward. The supplier then refills the empty one at the rear.

Repeaters are components that are used regularly but require to be manufactured less frequently. There is more likely to be minimum economic batch sizes associated with them and inventory management needs to be linked closely to the manufacturing plan.

Strangers are manufactured at infrequent and potentially long intervals. They may have a long lead time and require special tooling to be produced. These need to be identified and ordered early in the procurement process as needed.

Designers should aim to avoid the need for using "strangers".

3. Modelling

In the past, modelling generally involved making a physical model of something, usually something innovative. That is very time consuming, expensive and may not be very representative of the final product or manufacturing process.

Physical models can still serve a purpose, particularly for checking that something is possible of being assembled in the way envisaged. However, a lot can be achieved using virtual, digital models using Building Information Modelling (BIM). This can be used for many purposes including:

- Taking 3D scans of the in situ works that the offsite elements have to interface with
- Simulating and assessing the performance of a design (thermal, acoustic, loading, throughput, output etc)
- Validating logistics and maintenance access
- Simulating the assembly and installation processes
- Simulating the commissioning process
- Simulation for training eg for building management systems.

Modelling now plays a major role in the design and efficient delivery of offsite construction.

4. Fixings to structures

This subject is closely linked to "Tolerances" above, and again it is helpful if designers have an understanding of site build tolerances and fixing systems. Where a structure has a predictable installed dimensional range and the achievable dimensional tolerance range of an offsite assembly are known, a suitable fixing system that can accommodate the two extremes of these ranges may be used. Where there is good control over both the structural element and the element to be connected to it, fixings may be pre-positioned and incorporated into the structure during manufacture.

Examples of this being done include threaded sockets included in pre-cast concrete panels or electrical conduits and switch or socket back boxes being incorporated into modular wall panels.

5. Design freeze

Manufacturing lead times and capacity planning, combined with the reduced ability to modify things onsite at the erection stage, mean that those aspects of a project's design which interface with the offsite elements need to have their design frozen, prior to manufacturing, planning and ordering the long lead time components and materials. Once the manufacturing procurement process has started and the order has been received by the supplying factory, the ability to change designs drops rapidly and the cost of change can also increase significantly. A few manufacturers have production processes that apply mass customisation techniques in which the final product is differentiated by a few processes at the end of the overall manufacturing process. A simple example of this could be the colour that an air-handling unit is sprayed or a fitting welded to a pipe. However, this is relatively minor in the current state of building services modularisation, hence the need for an earlier design freeze.

6. Standards & Approvals

Be clear on what the applicable standards are and how approvals will be obtained. Section 9 provides more detail on this, including how the EU Construction Products Regulations apply to offsite construction.

A significant point to note, however, is that the performance of an assembly is not always equivalent to a simplistic combination of the performance ratings for the constituent parts. There is a risk that some parts may interact with each other in some conditions. For example, two metallic components may perform well individually but when placed together they may create a corrosive electrical reaction. Ensure that the standards are achieved by the complete assembly and that approvals reflect this.

This is most challenging in the area of innovation. Specialist engineering and scientific advice may be required. Buildoffsite has developed an accreditation scheme (BOPAS) for innovative offsite products. http://www.bopas.org

7. Programmes Construction programmes with a high offsite content can be a lot shorter than traditional methods, even allowing for the factory production lead time. The key to achieving this is to create an overall balance in the flow of assemblies and site works that establishes a repeatable rhythm.

The same applies within the offsite factory. A balanced flow-line with short change over times and a flexible multi-skilled work force combined with a controlled working environment can increase productivity dramatically. Even in a simple factory with little automation and modest investment in materials handling equipment, jigs, fixtures tooling and training, productivity can be between 2 and 4 times higher than on a construction site.

If you introduce the opportunity for 2 or 3 shifts working, the programme contraction can be increased proportionately where onsite works can accommodate the acceleration. (The less that is done onsite, the less this becomes constrained). This is demonstrated by the fact that offsite manufacturers often assemble a large proportion of their products before they start onsite as the installation process becomes much shorter than the manufacturing cycle to produce them. They could reduce this by employing more "just in time" manufacturing techniques, matching the production rhythm in the factory to the installation rhythm onsite. This has been done, (see the Buildoffsite case study of the BAA Corridor Product http://www.buildoffsite.com/pdf/casestudy3.pdf) but it is the exception rather than the rule today. If clients are prepared to pay a significant part of the price once the product is in a yard or warehouse awaiting delivery, this is unlikely to change.

8. Methods statements

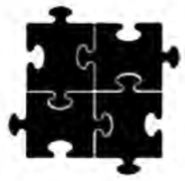
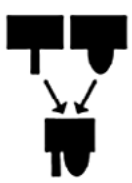
Methods statements are becoming very comprehensive but arguably less accessible by the people actually doing the work. Manufacturing method statements bring all of the relevant information for a production stage together in one very visual set of instructions. These may be called “One Point Lessons” or “visual task sheets”. They detail everything the operative needs to know about assembling a particular product or family of products, including what good and bad look like.

3D BIM is adding another dimension to this, providing both 3D drawings and the ability to view the model of what is to be produced in an interactive way. Risks can be highlighted, assembly sequences animated and information such as torque specifications or acceptable test result ranges viewed by simply pointing at the relevant component.

Tools that should be considered at this project stage

Approaches to be considered at this stage to have a lean implementation:

Pictogram	Representing
	Benefits assessment (TM Loughborough University)
	The commercial aspects
	BIM & configuration management – development of programme or portfolio wide standard object libraries
LEAN	**Lean Construction Methods**
	**Design for Manufacture**
	Design for productivity
	Design for logistics

	Design to be modular
	Design to make manufacture easy
	Optimise design for suppliers’ capabilities
	Use common parts and materials
	**Design for Assembly**
	Minimise and manage interfaces
	Simplify and reduce sub-assemblies and component parts
	Reduce assembly risks
	Make sub-assembly easy
	Design for easy handling
	Use efficient methods of jointing
	Prototyping and first-run studies
	Design for commissioning

	Design for maintenance and decommissioning
MRP	Materials (or Manufacturing) Requirements Planning – for prototyping and 1st run studies
ERP	Enterprise Resource Planning
6σ	Six Sigma ™ – Motorola

(Further details on how to apply these are provided in Section 10 Tools).

5.6 Build and Commission / Construction

Construction Industry Council (CIC) project stage 5 Build and Commission[22].
Equivalent to RIBA Plan of Work 2013[23] stage 5 Construction.
This is the stage in which the RIBA Plan of Work includes "Offsite manufacturing and onsite construction in accordance with the Construction Programme.

This section is therefore sub-divided between offsite, sub-section 5.5.1 and onsite sub-section 5.5.2.

5.6.1 Offsite, manufacture and supply

Key Points

1. **Procurement.** Establish reliable, capable supply chains.
2. **Production scheduling and the site programme.** Design in flexibility and identify long lead time items for projects. The ability of delivery schedules to respond to site variability.
3. **Identification of critical elements and dimensions.** Review the designs with particular attention to the interface details.
4. **Supply chain capability and critical dimensions.** Ensure that critical aspects are understood and their production adequately controlled.
5. **Quality.** Both by the supplier and client Factory Acceptance Tests (FAT).
6. **Waste.** Apply the Lean Construction principles for the elimination of waste.
7. **Logistics.** Base upon demand pull signals and design for flexibility and efficiency.
8. **Project management capability.** Project managers need to have a good awareness of Lean Construction principles and the different characteristics of offsite procurement to get the most out of offsite manufacture and supply.

1. Procurement

In this context the relationship between the offsite manufacturer and its supply chain and site needs are considered further. The concept of "runners, repeaters and strangers" has already been looked at above in section 5.4. Another similar concept is the "ABC" classification system for components, widely used in the manufacturing sector. Court, Pasquire and Gibb[24] identified "modules (type A), being delivered directly to site on a call off system. Components and consumables (types B and C), being "parts kitted or replenished for delivery to site" and "kits are postponed until the moment they are needed".

To back this up, the components and sub-assemblies from suppliers that make up the kits are called into the manufacturer to support the call off schedule from the project. Consumables are supplied in response to the receipt of requirement tokens in a system known as "kanban" (of which the 2 bin system described above is a variant, the empty bin being the equivalent of the requirement token).

As in all commercial enterprises, it is important that a potential supplier's financial strength is demonstrated before engagement. When considering logistics below, the whole supply chain needs to be included.

[22] Source for CIC project stages: BIM Task Group Report 104 Plan of Work – Industry Framework for the Refinement of Information on Construction Projects in the Built Environment
[23] RIBA Plan of Work 2013 Overview ISBN 978 1 85946 519 6
[24] Modular Assembly in Healthcare Construction – A Mechanical and Electrical Case Study

2. Production scheduling and the site programme

One of the first tasks to schedule is the procurement or production of long lead-time items. Critical paths apply as much offsite as onsite.

Production scheduling should reflect the site delivery requirements. If not, efficiencies gained in the factory can be lost onsite. For example, a complex system that is being installed into a building may have simple straight modules and more complex to manufacture curved elements. If the factory makes and delivers all of the straight modules first and these get installed leaving gaps for the corner modules, which are made and delivered later, there is a significant risk that integrating the corner modules will require repositioning of the straight sections already installed, leading to waste.

It may not seem convenient at the time, but by applying Lean Principles of achieving single piece flow and very fast change over times between module type assembly, it should be possible to manufacture efficiently in the sequence required to match the site installation plan. It also creates flexibility so that factory production can be more responsive to changes to the construction sequence onsite.

The equivalent of this was achieved with the BAA serviced corridor module production. Large batch production is not necessarily efficient. Large batches lead to large inventories being held ahead of site requirements and these may contain quality or coordination issues that only become evident when they arrive onsite and are put in place. Rework at this point becomes very costly and disruptive.

3. Identification of critical elements and dimensions

At the earlier design stages, attention has been given to defining the interfaces between different elements of the project, with particular emphasis on the interfaces between onsite and offsite aspects. These may be, for example:

- The upper surface level of foundations that will receive modules
- The positioning of site cast sockets or threads for connections
- The alignment of lift shafts through basements and superstructure
- Floor to floor measurements relating to escalator installation
- Adjacencies between modules that make up a larger plant room, where multiple pipes need to be connected
- The services connection points for bathroom modules.

Not all dimensions are critical. Focus on the ones that are.

4. Supply chain capability and critical dimensions

Ensure that all suppliers understand which dimensions are critical and that they have robust, quality assurance process in place to deliver them. Such processes should include demonstrating that processes and measurement systems are capable of doing what is required to get the outputs right first time every time. Using the Six Sigma (TM Motorola) methodology including the steps of define, measure, analyse, improve, control (DMAIC) is one way of achieving this.

5. Quality

It is reasonable to expect that suppliers these days should have ISO 9001 accreditation and this should cover design as well as manufacturing. However having a Quality manual alone does not assure right first time capability and there are other aspects that need to be in place to promote this. A formal problem resolution process based on the measured quality output is essential for continuous improvement (eg 6 Sigma DMAIC). There should be clear evidence that this is done routinely and includes input from knowledge at all levels of the production team.

The use of visual aids such as one point lessons throughout the business, and devices to mistake proof the process should also be in place. The visual management should also display the quality performance metrics and include the variation figures. A company that is operating at less than 3 sigma should give cause for concern but not as much as one that doesn't know its performance levels.

To aid non-manufacturing clients assess the capability of its offsite supply chain Buildoffsite and Lloyds Register have collaborated to produce the Buildoffsite Registration Scheme. See: http://www.buildoffsite.com/register.htm

The manufacturer's in house quality assurance processes shall ensure the right outputs are achieved with the appropriate degree of traceability of inputs. However there is also the opportunity for the client to witness acceptance tests at the factory. This can save time onsite by reducing the onsite commissioning required and hence any further client acceptance needs. The client may work with the designer and manufacturer to determine which tests may be carried out at the factory prior to delivery. Some tests may lead to contamination, which may duplicate the need for cleaning and overall testing. Gas based pressurisation tests, for example, do not necessarily provide reliable results for systems that will contain fluids. There is, therefore, a need for careful design and planning of factory acceptance tests (FAT).

6. Waste

A lot has been written on waste avoidance in the Lean Construction literature. The main forms to be eliminated include unnecessary: transport (T) inventory (I), motion (M), waiting (W), over-production (O), over-processing (O), defects (D) and skills misuse (S) (TIM WOODS). Koskela[2] has also highlighted the significance of waste in construction through people making do when the correct information or materials are not available. Further information on Lean Construction may be found at: http://www.ciria.org/service/lean

7. Logistics capability

Internal logistics with the ability to manage inventory with an emphasis on agility is covered above. Historically, offsite services modules have contained a significant amount of additional support structure which has been needed for both fabrication and support during delivery and installation. Increasingly assembly, transportation and installation frames (ATIFs) are used. These are removed from the module after installation and returned to the factory for re-use.[2]

The chances are that the offsite supplier will be providing some big components out of their despatch door. This isn't necessarily a problem as long as they keep within the Road Haulage Regulations for large loads to minimise the need for special escorts. Deliveries requiring escorts and road closures should be avoided where possible.

Suitable protection for the goods and appropriate lifting tackle to eliminate damage are important. Repairing even something as simple as paintwork on steel onsite attracts potentially large cost and delay.

Large projects may establish a logistics or consolidation centre near to the site from where deliveries onto the site may be coordinated. This can have the benefit of placing a buffer between the factory and the site, which can be used for accommodate minor schedule variations onsite (eg due to weather conditions or unexpected problems arising).

[2] (http://usir.salford.ac.uk/9386/1/2004_Making_do_the_eighth_category_of_waste.pdf)

With onsite installation times becoming very short, the manufacturing cycle times are often much longer, eg for a plant room or for vertical or horizontal distribution modules. Consequently, just in time manufacture becomes impractical. In this context, temporary storage and materials handling requirements may be needed if the factory or adjacent yard is not large enough to contain the output. The project may need to budget separately for this, depending upon how the supply chain is organised.

8. Project management capability

Often issues with offsite provided facilities occur through the conflict of interests between the onsite Project Manager and the offsite Factory Manager. The Project Manager’s world is all about delivering change, whereas the Factory Manager aspires to predictability of schedule and maximising the utilisation of their equipment.

Project managers need to have a good awareness of Lean Construction principles and the different characteristics of offsite procurement to get the most out of offsite manufacture and supply. Increasingly project management will need to embrace systems integration as suppliers deliver more assemblies and sub-assemblies to site and managing interfaces between them becomes more significant than it is today.

5.6.2 Onsite aspects (relating to offsite elements)

Key Points

1. **Delivery.** Keep it predictable in terms of both timing and access routes and manage weather risks.
2. **Lifting and positioning.** The craneage, hoist and module lifting strategy should have been developed as part of the early construction advice input. Aim to stick to it!
3. **Installation and integration.** Use repeatable, capable processes.
4. **Commissioning.** Only do what is needed onsite.
5. **Witnessing requirements.** Clients may require that they (or their representative) witness the offload, the installation process and / or the commissioning testing.
6. **Return of temporary frames etc.** Plan for the return of re-usable temporary frames and other equipment.
7. **Controlling access to completed works.** Where possible, keep finished areas sealed from site access.
8. **Protection.** Modules are usually delivered pre-finished so temporary protection may be required depending on the delivery programme related to the weathertightness of the envelope.

1. Delivery

Increasingly projects are using 3D BIM. Where this is the case, it is helpful if the model has been developed in such a way that the offsite modules are individually brought into the model in the sequence that the construction process intends. This can be done in such a way as to link the BIM to the project plan. The resulting animation of the build sequence can be very useful in explaining when deliveries should be made and what should be done when they arrive. The more sophisticated models may include the crane operations within the animation and tracing the route that modules will take through the facility to reach their final destination. This type of information is very useful for briefing the site team as to why the access routes need to be kept clear.

Having planned deliveries in detail, their arrival onsite should be highly predictable. There may be a need or opportunity to combine more than one element prior to the lift. This can be the case with items such as temporary edge protection where a module includes both structure and services. (As is illustrated in the Cheese Grater example in section 5.1).

Deliveries of large plant rooms, air handling units etc to city centre sites, which need to have a road closure for crane positioning, may be restricted to Sundays by the local authority. Research this well in advance and get the requisite permits in good time.

Example Delivery checklist (provided by Crown House Technologies), covering both factor and site aspects. A lean implementation of this would avoid the need for repeating the same check.
This is based upon a real example.

Your Logo	Your Company				
		Status	Uncontrolled / Controlled		
		Reference			
		Revision		Date:	
		Sheet No	1	of	2

Inspection Sheet – Module Final Check

Drawing/Module :		Date:	
Project :		Contract No.:	

Item	Requirement	Status	Date	Shop floor operative initials	Manufacturing Inspectors Initials	Site Inspectors Initials
	DOCUMENT REF No:					
1	Have correct spec bolts been used?					
2	Are all nuts and bolts fitted, and marked twice for correct sequence and torque?					
3	Are washers fitted where needed with set pins and nuts?					
4	Are set pins fitted only to fully lugged butterfly valves?					
5	Are standard bolts fitted to all other flanged joints?					
6	Are directional valves fitted correctly?					
7	Have all valve handles got clearance to operate fully?					
8	Have all brackets been installed in locations shown on the drawing?					
9	Are all brackets complete, square and tight with stud ends capped?					
10	Have correct U bolts been installed? (BZP for internal modules and Galv for external)					
11	Are bellows square and fixed for transport and installed to manufacturers Dimensions?					
12	Are inertia bases fixed for transport with all springs square and level?					
13	Are all test points fitted and accessible with a full length probe?					
14	Are all AVs and DCs fitted or supplied? (Are any additional needed?)					
15	Is there at least 25mm clearance between lagging and any other object?					
16	Are all open ends capped and free from damage?					
17	Are you happy with visual inspection of welds and have 10% been NDT'd?					
18	Have you completed 10% random inspection of bolts torque?					

19	Are lifting lugs correctly fitted? (enclosed frame modules only)					
20	Is mod number and weight clearly indicated on module?					
21	Are all ancillary items not being fabricated installed attached to/with the module for delivery?					
22	Check any items removed for testing are labelled, including connecting pieces and crated for site delivery					
23	All debris removed from module i.e. cut out coupons removed from pipe.					
24	Is there any visual damage before it leaves the works? Paintwork insulation, rust etc.					
25	Pressure test pack available for services. Eg Mechanical, electrical and ductwork.					
26	Any transit supports, fixings and bolts are in place.					
27	Last check all items are secure.					
28	Fill out snag sheet if required.					
29	QA Paperwork complete, (send copy to site.)					
30	Check manufacturing centre QA sign off sheets.					
31	Is module delivery note indicating any ancillary items prepared?					
32	Are all valve labels fitted as shown with clearance for lagging					
33	Are pressure test sheets sent to site with module?					
34	Module accepted? Site must return completed form within 24hrs of delivery to site. Form to be scanned and emailed to Manufacturing centre and DfMA package manager audits will be carried out					

Comments /Actions					
FABRICATOR REVIEWER		SIGNED		DATE	
SITE REVIEWER		SIGNED		DATE	

Key to inspection status:

H – Hold Point
N/A – Not Applicable
W1 – 100% Witnessed
W2 – Random Witnessed
A1 – 100% Inspection
A2 – Random inspection
R – Review

Standard operations and visual aids such as One Point Lessons are equally important onsite as offsite.

2. Lifting and positioning

The craneage, hoist and module lifting strategy should have been developed as part of the early construction advice input. Aim to stick to it! The forces involved are different if a module is lifted in a horizontal or vertical orientation. Centres of gravity can be calculated in BIM and lifting fixtures positioned accordingly so as to facilitate work at this point, particularly with crane use. Occupational health considerations should have helped determine a lifting system, which is safe, at the design stage. This may, for example be a scissor lift that can be positioned under an ATIF for lifting modules to be hung from soffits or installed inside ceilings. Use repeatable, capable processes.

Final positioning can be a critical aspect in achieving the critical dimensional tolerances. The design may have incorporated positioning guides (eg cones or tapered components). The lifting system may have adjustable fine-tuning screws that control the last few centimetres.

The floor plate may have dropped down levels to receive modules that contain their own floor (eg bathroom pods).

Have a clearly documented methods statement for each type of operation.

Remember that tower crane capacity is often on the critical path for multiple work packages.

3. Installation and integration

The design process should have identified access routes and methods. Stick to them. Organisationally, the skills required for installing some modules may have more in common with other work such as ducting installation or a combination of modular wiring and pipework connectors. So the initial consideration is what type of resources are needed and with what skill sets? It may be optimal to train a team specifically for a particular range of installation requirements on a project.

It is assumed that the design team will have resolved all space integration considerations. At this stage it is a question of integrating with service modules that have just been installed. The physical fixings and connections have been dealt with. However, for the commissioning process to start efficiently, it is important that all switches, variable controls and valves are left in the designated state. This should be checked as part of the installation process where there is a risk that they may have been moved from their factory set positions.

Integration testing may be feasible on a circuit or zone basis prior to completion of the whole facility.

4. Commissioning

Much beneficial commissioning can be done on small plant skids / assemblies using test rigs. For example pumps can be run / flow tested on test rigs and controls can be proven.

Whilst distribution systems will need to be connected on site before they can be commissioned, more complex plant rooms and passenger moving systems may largely be commissioned before delivery. Only do what is needed onsite. This will include a full system pressure test for pipework.

As with integration testing, it may be feasible to commence commissioning on a zone-by-zone basis once sufficient modules have been installed and the building envelope is made weather tight.

Offsite manufacture in a controlled environment enables the supplier to maintain the cleanliness of pipework, reducing the need for flushing during commissioning. With modular wiring it is advised to test the whole system once connected rather than sub-elements of this.

5. Witnessing requirements

Clients may require that they (or their representative) witness the offload, the installation process and / or the commissioning testing. Ensure that all concerned are aware of this in good time. The more predictable offsite manufacturing based approach should make this easier to organise.

6. Return of temporary frames etc.

Plan for the return of re-usable temporary frames and other equipment. Increasingly, both for cost and sustainability reasons, there is a need to return and reuse temporary frames, fixtures, props and other temporary works. Often there will be specialist trailers being returned to the haulier's home base, which might otherwise be empty. Aim to use such transport so as not to increase the additional energy consumed in this recycling of materials.

7. Controlling access to completed works

Where possible, keep finished areas sealed from site access. This may be a bathroom pod or a hotel suite, which has been delivered with all of the sanitary fittings, furniture and equipment pre-installed, or it could be a lift car, a commissioned plant room, or zone of a facility.

Ensure that the lock key type and control strategy for the facility is respected and that access restrictions are clearly marked on removable signage.

Establish a permit system on larger projects.

8. Protection

Generally temporary protection should be limited however where there are areas where the building is not fully weathertight or temporary storage is required prior to installing in final position, temporary protection may be required. A range of options exist including factory applied wraps and protection, specifying moisture resistant materials or site completion of sensitive elements

Tools that should be considered at this project stage

Pictogram	Representing
LEAN	**Lean Construction Methods**
	BIM & configuration management Model, test, simulate and correlate
MRP	Materials (or Manufacturing) Requirements Planning
ERP	Enterprise Resource Planning
KANBAN	Kanban, pull scheduling
6σ	Six Sigma (™ – Motorola)

5.7 Handover and Close Out

Construction Industry Council (CIC) Stage 6 Handover and Close Out, output: to deliver updated 'As-fitted' Information. Equivalent to RIBA Plan of Work 2013, stage 6 Handover and Close Out. (Stage 5 in Soft-Landings, BSRIA BG 4/2009, if adopted; also referred to as 'professional aftercare' stage in some of the Soft Landings literature[25]). UK Government information exchange required, including Building Information Model and CoBie format.

The BSRIA Guide BG 6/2012 includes a schedule of activities for this stage (Pro-forma 7). It also covers information on the MEP 'As-built Model' and the data to be provided in CoBie format.

This stage covers issues arising after Practical Completion, including the following main deliverables for a building services designer[26 27]:

- Review and update list of defects from post-completion audit
- Train FM team and building users on the installed systems
- Carry out post-completion audit
- Years 1 to 3 Aftercare: Monitoring, review, fine-tuning and feedback
- Review operation processes
- Organise independent post-occupancy evaluations

Although the above apply equally to traditional design and offsite, the greater participation in design by offsite manufacturers could have the effect of detaching the consultant engineers from the detailed design stages. If the manufacturer is also the building services designer, their role will need to be defined in this context.

Key Points

1. **Establish whether the Soft Landings framework is being adopted and the impact on your scope of services.** In Soft Landings, the duties of the design and building team are augmented, particularly at briefing, pre-handover and professional aftercare stages.
2. **Get to know your client, their operational and maintenance processes, procedures and resources.** To be able to support the FM team and the building users on how to operate and maintain the building systems and controls.
3. **Keep a close collaborative relationship between consultants and the manufacturer(s).** The information to be handed over to the client combines elements provided by the manufacturers as well as the consultant.
4. **Use the earlier stages to build up your own knowledge of the systems supplied.** So that it will be easier for you to prepare for commissioning and help fine-tune the systems.
5. **Keep adequate fees allocated for this stage**. The scope for this stage is not reduced as a result of offsite. It may be increased to include information in the format required by the client (eg BIM and/or CoBie), and if the Soft Landings framework is adopted it requires greater input from the consultants.

[25] Full set of relevant documents can be found at www.softlandings.org
[26] BSRIA Guide BG6/2012 (Churcher 2012)
[27] (Usable Buildings Trust 2009)

1. Establish whether the Soft Landings framework is being adopted and the impact on your scope of services.

In Soft Landings, the duties of the design and building team are augmented, particularly at briefing, pre-handover and professional aftercare stages. This augmented scope is not part of the standard M&E engineer's scope, but when required, it may demand more resources from briefing through to completion, particularly after handover.

Clearly identify the activities required at this stage and agree the split of responsibilities between consultants and suppliers/manufacturers. As offsite M&E contractors may have greater design input than would be the case with traditional design, it is important to agree the role of each party post-completion, for operation and maintenance support.

For 'Design and Build' projects, the split of responsibility between contractor and consultants needs to be defined and agreed by the project team.

2. Get to know your client, their operational and maintenance processes, procedures and resources.

To be able to support the FM team and the building users on how to operate and maintain the building systems and controls.

Unless not included in the scope of services, you will probably be expected to support the FM team and the building users on how to operate and maintain the building systems and controls. With offsite, contractors and manufacturers tend to have greater input at detailed design stages, but this does not necessarily reduce the consultants' duties at commissioning, pre-handover and post-completion stages.

Your task will be easier if at Practical Completion you are already familiar with your client's operational and maintenance processes, procedures and resources, particularly the skills of the individuals that will be operating and maintaining the building systems.

3. Keep a close collaborative relationship between consultants and the manufacturer(s).

The information to be handed over to the client combines elements provided by the consultant as well as the manufacturers.

This is not about simply collating relevant information from all relevant parties, but about identifying and combining the information a client might need to maintain, operate and modify the asset. Furthermore, this needs to be done in a way that the relevant information can be accessed through the Building Information Model. For guidance on the content of the M&E Building Information Model refer to BG 6/2012[28]or later issues.

For this you will need to understand how the building is going to be managed and maintained; and how the installed systems should be run to achieve the designed performance. Increasingly it will become your responsibility to ensure that the systems are fine-tuned to deliver the designed performance!

[28] (Churcher 2012), page 83.

4. Use the earlier stages to build up your own knowledge of the systems supplied.

This will make it easier for you to prepare for commissioning and help fine-tune the systems.

As offsite requires contractors and manufacturers to have greater input at detailed design stages, consultants may not keep close enough to the process and this could cause difficulty at commissioning and post-completion stages. To avoid this, prepare a plan for your commissioning, handover and post-completion activities and identify the knowledge you will need to develop in relation to detailed design by others. Keep your plan updated in light of what you learn through the earlier stages to avoid surprises and additional work later on.

5. Keep adequate fees allocated for this stage.

The scope for this stage is not reduced as a result of offsite. It may be increased to include information in the format required by the client, (eg BIM and/or CoBie), and if the Soft Landings framework is adopted as it requires greater input from the consultants. BSRIA's BG 6/2012 and BG 4/2009 cover the new scope in considerable detail (BIM/CoBie and Soft Landings respectively) but the actual scope will have to be assessed on a project by project basis.

You should have a plan for your post-completion activities as soon as possible and you should re-evaluate your plan as the design develops and as you get to know your client. The size and complexity of the project and the systems installed will determine how much time and resources will be required and over what period. Remember that if the Soft Landings framework is adopted, your input will depend also on what actually happens once the occupier moves in, so keep close to the client and keep up with their moving in plans.

Tools that should be considered at this project stage

Pictogram	Representing
	Benefits assessment (TM Loughborough University)
	BIM & configuration management Model, test, simulate and correlate
ERP	Enterprise Resource Planning
6σ	Six Sigma (™ – Motorola)

5.8 Operation and End of Life / In Use

There is no specific stage for decommissioning and disassembly, but as M&E systems tend to have a shorted design life than fabric or structure, their decommissioning and disassembly would probably come under the Construction Industry Council (CIC) stage 7 Operation and RIBA Stage 7 In Use.

Key Points

1. **Consider each system individually as well as the interfaces.** It should be possible to replace each system individually.
2. **Removal of large items.** Consider physical access for removal of large items for replacement due to defects or end of life.
3. **Include information about replacement of items and systems in the O&M manuals/ Building Information Model.** This information will include elements provided by the consultant as well as the manufacturers and will need to be coordinated.

1. Consider each system individually as well as the interfaces.

It should be possible to replace each system or each component on an individual basis.

From a design perspective, it is important to consider the different design lives of M&E systems and how these systems can be safely decommissioned and replaced independently of each other. Consideration must be given to both decommissioning and disassembling. Consider that even before the design life has expired there may be the need to replace individual systems and/or components.

Each component and assembly needs to be designed for both installation and disassembly. Considerations should include size, sequencing, fixing, interfaces and the possibility of re-use of entire systems, components and/or materials.

2. Removal of large items.

Consider physical access for removal of large items for replacement due to defects or end of life.

Items that are not easy or safe to be taken apart will need to be safely removed. Information about safe disassembly and removal should be provided to the building owner as part of the O&M manuals/Building Information Model.

3. Include information about replacement of items and systems in the O&M manuals/ Building Information Model.

This information will include elements provided by the consultant as well as the manufacturers, and will need to be co-ordinated.

As early as possible, agree how this information is going to be compiled, coordinated and communicated. Agree responsibilities as soon as possible and allow enough fees and resources.

The Building Information Model (BIM) is an ideal means to communicate decommissioning disassembly sequencing. For this it will need to be created with this purpose in mind. The use of the model for this purpose is likely to increase as clients come to appreciate the benefits for maintaining, altering and expanding the building. Therefore, project teams need to plan for the use of the model. To be of use to the client, the Building Information Model needs to be created for the purpose it is intended. It will not automatically result from the design and construction model(s).

During the life of the facility, component obsolescence issues will also require the BIM to be updated as substitute or alternative parts are used.

According to BSRIA BG6/2012, typical uses for the MEP as-built model include Facilities Management:

"The model may be used for maintaining, altering and expanding the building, within the terms of any licence agreements agreed with the model originator(s)."

Tools that should be considered at this project stage

Pictogram	Representing
	BIM & configuration management Model, test, simulate and correlate
ERP	Enterprise Resource Planning
6σ	Six Sigma (™ – Motorola)

6.0 Case Studies

6.1 Component-based offsite construction

Pipe Modules for a Commercial Office Building

Project details

The building is a 12 storey, 60,000m^2 regional office for The Royal Bank of Scotland in Manchester city centre, including a basement and roof top plant room. The primary heating and cooling to the ten floors of office space is via fan coil units.

Objectives

The main project drivers for N G Bailey were to minimise the number of operatives on site due to the limited welfare space available and to reduce the supervision required minimising waste, plant and the exposure to accidents. An additional factor was the limited availability of skilled labour due to the large volume of work being undertaken in Manchester at the time.

Method

The primary distribution pipework from the risers was installed in prefabricated mapress pipework modules in lieu of traditional on site installations.

Outcome

- Reduced costs, with savings in both direct and indirect costs giving an overall saving of nearly 9%.
- Improved system quality in installation – no snagging and no leaks.
- Improved system quality in use – as the prefabricated systems are clean on installation, they have no swarf in the pipes. This means the filters remain clean, and results in more efficient systems, as less energy is needed to pump the water around for its lifetime. It also means the pumps are under less strain, and so last longer.
- Improved Health and Safety – The safety risks were significantly lower with fewer people working in difficult or dangerous conditions and activities being undertaken in cleaner and neater environments.
- Site Benefits Availability of skilled labour was a serious constraint on the use of traditional methods which was mitigated by the use of pipe modules. There were a reduced number of trade interfaces and less need for access and plant.
- Reduced exposure to risk – The use of offsite options increases certainty and reliability. This case study delivered an example of this when the glazing contractor went into liquidation, leaving much of the building exposed to the weather for many weeks. Had the pipework been a traditional in situ installation, the work would have had to stop as material and equipment would have been exposed to weather damage prior to fixing. The use of modules meant that the work proceeded as normal and the Client's loss and disruption was greatly reduced.

Key lessons learned

- Defect free pipe modules meant no snagging requirement or cost.
- Fewer site personnel made the site supervision easier and better.
- The health and safety benefit was felt to be significant and had the additional benefit of also reducing the management stress.
- The programme can be reduced as a result of the use of modules because the plasterboard and finishes could go in quicker. To take advantage of work flow improvements and innovative work packaging solutions such as those offered by offsite solutions, effective planning and programming is essential. More traditional planning and programming systems are unlikely to realise the available benefits.

Source and further information

Buildoffsite Business Case Study 001 C.L. Pasquire; C.I. Goodier, A.G.F. Gibb

6.2 Unitised non-volumetric offsite construction

Ormskirk Hospital Extension

Project Details:

The Maternity and Paediatrics facility at Ormskirk District General Hospital was a ProCure 21 initiative for Southport and Ormskirk NHS Trust, totalling £11 million, with the M&E portion at £5 million. The 5 storey, steel-framed extension links into the main hospital street, with 120 beds throughout. The hospital, located on the outskirts of the town centre, remained operational throughout the construction period.

Objectives:

- Health & Safety and site tidiness initiative (Costain)
- Minimise construction costs
- Completion date certainty
- Predictable quality
- Work within restricted site and delivery space
- Avoid perceived shortage of local skilled labour.

Method:

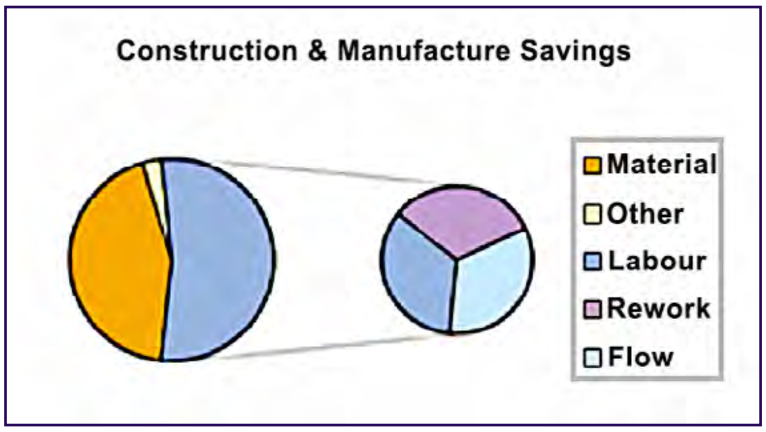
Modular assemblies, consisting of banks of 3 or more pipes fitted to unistrut frames with tees and branches pre-cut, that were built and lagged in NG Bailey's off-site production facility. The units were delivered on wheeled trolleys and lifted into position on site where the joints were crimped.

The traditional benchmark assumed site installation of single lengths of Mannesmann mapress pipework, cutting-in and crimping tees and branches piecemeal and in situ, using time-served tradesman. Only bracket-work would be pre-fabricated, either on-site or by a supplier using unskilled labour.

Outcome:

- **Health & Safety:**
  There were no reportable incidents either on site or in the factory.

- **Construction cost:**
  The M&E sub-contractor reported a 13.4% cost saving.



The cost reduction was achieved largely by reducing material and labour costs. The latter through reduced direct labour costs, the elimination of rework and by improving the flow of work, in the proportions illustrated above.

Other benefits included:

- Time savings

	Traditional	Offsite	Benefit
Offsite	17	22	– 29%
On site	140	106	24%
Overall	157	128	19%

- The offsite time (weeks) included pre-construction activities.
- The target completion date was achieved. The need for rework was dramatically reduced demonstrating the predictability of quality.
- Site access constraints were accommodated efficiently.
- Local skilled labour shortage was avoided.

Key lessons learned:

- The flat soffit design dramatically reduced the services installation period – optimise the whole project
- The extra 5 weeks invested in the factory had substantial benefits, cutting 34 weeks from the time on-site and saving 29 weeks in total or about 5 weeks per 1,000m^2
- Offsite production can help achieve a wide range of improvements.

Source and further information

A more complete study of this project is available at:
http://www.buildoffsite.org/pdf/casestudy2.pdf

6.3 Volumetric offsite construction

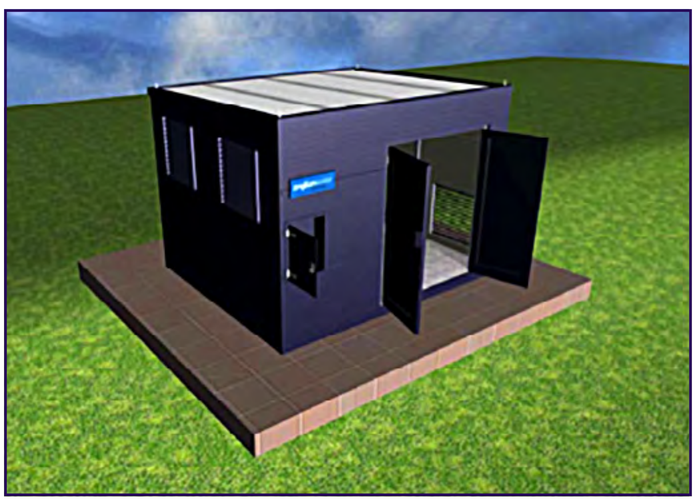
Anglian Water Booster Pump Station

Situation:

OFWAT demanded that water utility companies demonstrate improved value in capital investment programmes.

Objectives:

- Demonstrate improved value
- Design once, use many times
- Reduce carbon footprint
- Reduce waste
- Reduce impact of construction on residents
- Reduce noise for local residents
- Better working conditions in factory
- Better health & safety in factory



Method:

Anglian Water established a programme to improve sustainability and cost through the creation of a portfolio of standard products. One of the products is a booster pump station, a collaboration facilitated by Buildoffsite between NG Bailey and Anglian Water.

Outcome:

Reported benefits included:

- Costs dramatically reduced (see below)
- Design reused
- Better thermal properties – reduced winter heating & carbon footprint
- Guaranteed consistent quality of product • Reduced maintenance costs (design for manufacture)
- Reduced waste on site
- Impact on local residents was reduced through:
- A faster construction programme – 2 days erection on site vs 5 weeks
- Reduced traffic movements
- More work was completed in the safer and controlled conditions of the factory.

Cost	Index	Benefit
Historic	100	
1st delivery	76	24%
2nd delivery	66	34%

Key lessons learned:

- Standardisation saves money
- The end product is improved
- Continuous improvement is achievable
- More value can be delivered from a finite capital budget.

Source and further information

A more complete study of this project is available at:
http://www.buildoffsite.com/pdf/081009__markenzeranglianwater.pdf

6.4 Modular offsite construction

6.4.1 Heathrow Aircraft stand nodes

Situation:

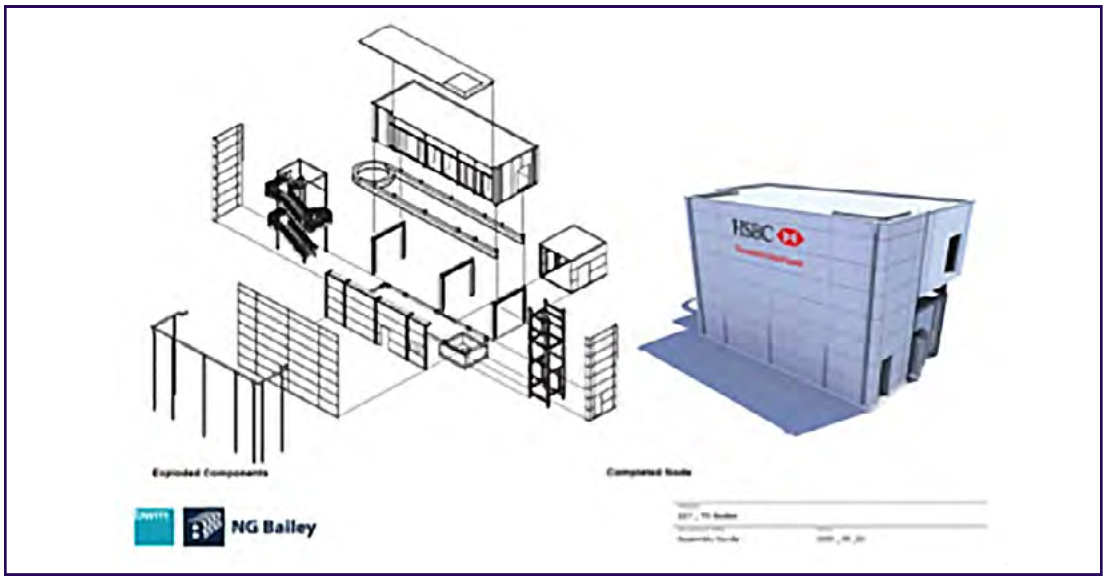
Within the overall programme for Heathrow Airport's expansion of Terminal 5 by constructing Satellite C, there was a need for 16 Nodes to be built on aircraft stands. However the availability of these stands had to be maximised for the airport to operate.

Objectives:

- Same passenger experience (quality) as T5A & B
- Maximising aircraft stand availability
- Reduce capital cost
- Health and safety continuous improvement
- Client requirements for DfMA to be applied to the overall project
- Minimising the number of personnel requiring airport security clearance

Method:

The contractor, Carillion, responding to Heathrow's requirements, working primarily with NG Bailey and Bryden Wood, set out to modularise these nodes.



Outcome:

Reported benefits included:

- The T5 quality level was achieved
- Significantly increased customer value was delivered

	Traditional	Offsite	Benefit
Time on site	16 weeks	2 weeks	87.5%
Construction cost	100	89	11%
Stand availability	0	**INCOME: £2.5m**	**£2.5m**

- Offsite findings:
  - Staff local to work place
  - Productivity gains
  - Better working environment
  - Reduced waste
  - Continuous improvement
- At site:
  - Fewer lifts, less risk
  - Fewer personnel airside & less security cost
  - Safer assembly processes including less work at height
  - No hot works on airport
  - Fewer deliveries airside & less logistics & security costs
  - Fewer deliveries in the Heathrow area better for local residents.

Key lessons learned:

- Understanding what represents value to a customer is fundamental
- Offsite construction saves money
- An holistic approach to design for manufacture and assembly can deliver significant and wide ranging benefits
- Opportunities like this can create potential high value added products for the manufacturer and client to exploit in the future
- The offsite facilities of a building and engineering services supplier were well suited to deliver these Nodes with relatively little change.

Source and further information

A more comprehensive version of this case study is available at:
http://www.buildoffsite.com/pdf/Case%20studies/casestudy_T5Cnodes.pdf

6.4.2 Preassembled plant rooms

HBOS additional premises

Project details

HBOS commissioned additional office and equipment accommodation on two of their existing sites in Copley and Pudsey, Yorkshire. Due to the internal environmental conditions demanded there was a heavy chilled water load, requiring large plant items including 3600 kW plate heat exchangers, pumps, de-aerators, side-stream filters and control equipment. This required some very large plant rooms.

Objectives

- Reduction in overall programme times
- Reduction in health and safety risk on occupied site
- Greater efficiency in construction and fit out processes.

Method

It was decided to rationalise and centralise the plant rooms and use preassembly offsite for the plant room equipment so it could be delivered ready fitted. Plant rooms for the Copley site were combined into a single enclosure with dividing wall, measuring 20m ? 12m. The unit was delivered in five sections. Plant rooms for the Pudsey site were separate with each one measuring 11m ? 8m and were split into two sections. Manufactured by Armstrong Integrated Systems, each plant room and set of details was modelled in 3-D allowing the client a virtual walkthrough before any manufacture or procurement started.

Outcome

- Cost and programme objectives achieved
- Plant rooms removed from the critical path
- Health and safety risks reduced for an occupied site
- Reduced site preliminaries and services.

Key lessons learned

By running operations in parallel the critical path could be considerably shortened
Disruption to an occupied site was reduced

Source and further information

(Source: Buildoffsite Yearbook 2009 Case study 2)

6.5 Sector specific offsite construction

St Helens & Whiston Hospitals – M&E input

Project details

St Helens and Knowsley Teaching Hospitals NHS Trust provides a full range of patient and emergency services to the local communities across the North West. In 2006 the Trust, awarded a £350m PFI scheme to the New Hospitals (Innisfree/Taylor Woodrow – VINCI Construction UK) to rebuild St Helens and Whiston hospitals as flagship, state-of-the-art, healthcare facilities. NG Bailey was awarded the £120m M&E contract.

Objectives

- To deliver a very large project on time
- Overcome the problems of little on-site storage
- Minimise disruption to the existing hospital on the same site

Method

To emphasise partnership collaboration and address the issue of onsite sequence. It was agreed that a large percentage of the project would be completed through the use of off-site construction, making it one of the UK's largest modular M&E installations.

Following in-depth consultation at the design phase with all parties, detailed data sheets were compiled for each room covering lighting levels, air conditioning and specialist extraction systems. An early design freeze was put in place and NG Bailey used its 53,500sq. ft. factory to manufacture and store each part. This careful planning allowed 90% of the high level engineering services to be prefabricated, with 65% of the installation completed on the first site visit. Each of the electrical and mechanical elements brought their own challenges, including the sheer size of the prefabricated ventilation plants that needed to be transported to the site.

Outcome

The project won the Off-site Construction Award for the best project in the healthcare sector and during the build not a single clinic or operation was cancelled. Most importantly, and unlike many construction projects of this scale, the hospital opened in April 2010, six months ahead of schedule and within budget.

Key lessons learned

- Early design freeze
- Early planning and a collaborative approach is essential to maximise the benefit of offsite prefabrication and construction

Source and further information

(Source: Buildoffsite case studies:
http://www.buildoffsite.com/pdf/Case%20studies/casestudy_sthelens.pdf)

Birmingham's New Street Station

Project details

To replace the station's 'engine room' which carries all the mechanical and electrical services to each of its 12 platforms. It is at the heart of the railway's operations and pivotal to its round-the-clock success.

Objectives

- To deliver a very large project on time
- Avoid impact on station operations
- Overcome structural limitations in the existing structure
- Deliver it safely.

Method

To develop a modular solution, using a new modular structural spine to support the new services modules. The spine was seven metres wide, three metres high and 126 metres long, weighing 300 tonnes. Spanning the width of the station, it consists of 11 modules (consisting between two and five sections) and five risers that linked seamlessly together. The structure incorporates two maintenance walkways and suspended plant rooms. Its frame has also been fitted with external cladding, acting as a defence for one hour in the rare event of fire.

The logistics surrounding transportation and the installation of the modules had to be planned meticulously at the earliest stages of design to ensure the concept would work. A factory prototype eliminated potential problems and each module arrived on schedule – free of defects.

Much of the site work took place between 10pm and 6am to ensure there was no disruption to train operators. It took a team of eight just three working weeks to install the modules, which were connected using more than 1,000 nuts and bolts.

Critical to success was the BIM (Building Information Modelling) technology which enabled the creation of a 3-D model with pinpoint accuracy. This maximised productivity and reduced lead-in time from design to installation. It generated a Bill of Materials (BoM) identifying every component and cost. It also weighed the modules precisely, shaping the logistics plan to ensure a successful installation.

The most complex challenge centred on the weight of the modules. Delivered in 24 separate sections, each weighing more than eight tonnes each, they were too heavy for the station floor.

The floor had a maximum loading limit of $3.5Kn/m^2$ – and the soffits could not be used either as a means of support. In addition, the delivery road had tight loading constraints with a GVW of 30T reduced from 57T.

So a temporary lattice frame was created which took the weight of the modules as they were craned over the tracks and installed on site.

Outcome

- The project broke new ground in the way it maximised innovation and minimised disruption in a railway station redevelopment
- Demonstrated the increasingly important contribution that an offsite solution can make to quality, safety, efficiency and the bottom line
- Accelerated the timetable from contract award to completion – with the service corridor ready to go live two years before the full completion of the overall scheme
- Took environmental sustainability to new levels with 'The Spine' having a design life of 60 years
- Improved health and safety by having fewer people working on site: the average labour force was just eight
- Lowered the carbon footprint by reducing waste and mileage to and from the site.

Key lessons learned

- The value of BIM
- How to overcome structural, operational and safety constraints.

Source and further information

(Source: Information taken from NG Bailey case study)
http://www.ngbailey.com/news/article/8104/birmingham-new-street-station

7.0 Glossary of offsite construction terms relevant to building services and guide to common building services module types

An extract from the Buildoffsite Glossary of Terms with additions

ATIF

Assembly Transportation and Installation Frame (ATIF). Can also be referred to as a stillage. A reusable frame returned to factory after module installation usually purpose designed for that product. Avoids non-value adding permanent support frame, providing protection and support during transit and lifting. The frame incorporates lifting points suitable for the module delivery and installation methods proposed ie crane, fork lift etc. Integral wheels are often included for smaller units to allow movement across a floor during delivery.

An ATIF would usually be 2m high 4m long and 1.5m wide, a frame on wheels made of welded box section for durability in reuse and weighing 500 to 800kg.

Building Information Modelling (BIM)

Building Information Modelling (BIM) is used to generate and manage data throughout the entire life cycle of the building, from inception, design, through construction to demolition and recycling. Digital models are created that contain not only the building geometry, but are data-rich in terms of relations, physical attributes, time, costs and quantities. The result is a collaborative tool that can be used by the whole project team, clients and end users. Benefits include a significant reduction in risk through improved co-ordination, control and flow of information, improved accuracy of cost and programme planning, increased productivity, efficiency and predictability because of managing teams and data centrally and reduced rework on site.

Busbar (Electrical)

Manufactured solid conductor system comprising encased copper or aluminium conductor sections, connectors and tap-offs or sockets. Available for a wide range of duties for power and control systems and would typically replace a wired system in whole or part. Consider carefully jointing between sections if part of a multi service module, connectors and tap-offs are usually proprietary, however smaller size sockets can be standard allowing interchangeability. Typical lengths are 3m, weight varies with current and rating.

Cable Containment (preassembled)

Cable system incorporating preassembled bracketry. Brackets supplied complete with preassembled spring nuts and bolts. Systems vary and can include:

- both bolted and welded forms
- trapezes and other non-standard bracketry
- fixing rails, cantilever arms and various accessories.

Typical lengths are 3m sections but are easily joined or reduced to suit.

Ceiling Void Modules

See Combined and Single Service Horizontal Rack.

Chilled Beam Assembly

The ventilated cooled beam is a complete cooling, heating and ventilation system in one monoblock unit. It is suitable for many types of applications design but is most commonly used for offices.

This is a proprietary product, usually 1.2 to 1.5m modules designed to be linked together with a valve dummy section at one end to match the profile and make up a room dimension. Typical weight 80kg per section.

Chimney (prefabricated)

The factory production of chimneys (mainly for residential projects). In situ chimneys are particular problem areas for consistency of quality, for example in terms of insulation.

Proprietary product for which sizes and weights are available from catalogues.

Combined and Single Service Horizontal Rack (also called Ceiling Void Module)

Integrated ductwork with pipe work and cable management support trays into a multi-services module mounted in the ceiling or under the floor. Usually constructed as an open frame structure, which reduces the overall weight of each section.

Same dimensions as a service distribution module.

Condensing Unit (preassembled)

The part of a refrigerating mechanism that pumps vaporised refrigerant from the evaporator, compresses it, liquefies it in the condenser and returns it to the refrigerant control.

Preassembled condensing units have components factory mounted to ensure minimum onsite installation. Units leave the factory with lines pre-charged ready to install with quick connect fittings. Control panels are factory pre-wired with a single connection point.

Varies greatly according to duty and dims/weights available from catalogues.

DfMA Design for Manufacture and Assembly

Design for Manufacturing and Assembly (DfMA) is a proactive and concurrent design and engineering process that focuses on meeting customer requirements while balancing cost, quality and performance.

DFMA is also the name of the integrated set of software products from Boothroyd Dewhurst, Inc. that are used by companies to implement the DFMA methodology. DFMA is a registered trademark of Boothroyd Dewhurst, Inc.

Distribution Module

Volumetric services preassembly for vertical risers or horizontal distribution which can be sub divided into heavy or light categories depending largely on the construction method and size/complexity/number of services they contain. See LDSM/HDSM for dimensions/weights.

Domestic Energy Centre

Modular unit to satisfy the complete hot and cold water and electrical requirements for an apartment, gas or electrical heating. 0.8x 0.8 x 2.7m high and typically 120kg.

Frame and Framing Systems

The term "Frame" typically refers to the structure of a building and may be constructed from many different materials. The term may also be used to describe the supporting structure for a pod or other volumetric unit. A standard proprietary system is 41mm x 41mm x 1.5mm gauge, multiples of this also are often used or a 41 x 21 for a skinny module. Box section varies dependent on loading and application.

Heating Pod

A "mini-plant room", typically fully commissioned and "ready to go", with modular boiler plant. The smaller units can be wall mounted, whereas the larger units are rig or floor mounted.

Size varies with unit output ie a 1000kw external access boilerhouse could be 6.5m x3.5mx 3.3m high and 8 tonnes.

Heavy Duty Services Module (HDSM)

Volumetric services preassembly for vertical risers or horizontal distribution. They may contain pipework, ductwork and electrical elements along with non services related items such as access walkways, grid floors and drylining. The will usually be constructed with a Cold Rolled or hollow box section steel frame and can for either a free standing or integral part of the building structural frame. Sizes as Plant modules.

Integrated Plumbing System (IPS)

Wash hand basins, urinals, lavatories assembled offsite into "units" with range of backboards, taps etc. Most units are designed to be removed and replaced with new units once they have reached the end of their serviceable life. Modules 800mm wide 2.7m high depth 500mm plus sanitary ware.

Jig

Manufacturing aid to allow repeated operations to be performed consistently. Usually this would comprise a bespoke frame for that product alone and might incorporate lifting points, stop ends, drilling/fixing points, supports during assembly.

Lift Shaft (prefabricated)

Containment for lifts and sometimes also bracing for structural frames. They are manufactured offsite, and often in pre-cast concrete or steel.

This varies in dimension to suit the car size based on the relevant British Standards although some manufacturers requirements vary.

Light duty service module

An assembly of small diameter pipework, cable trays and / or ductwork and associated fittings for both horizontal and vertical distribution. Usually assembled on or within a framework of proprietary steel sections such as unistrut. Typically 6 to 7.5m long and range from 250mm to 1.5m deep and 2.5m wide weighing 500kg up to 1.5 tonnes. Frame configurations vary to suit the application including a flat frame for shallow modules, box frame for multi service and deeper frames, or Christmas tree frames to allow easier in situ cabling.

Lighting Rafts and beams (preassembled)

Multi-service light rafts and beams incorporating some or all of, luminaires, chilled beams/ radiant panels, smoke detectors, sprinkler heads, PIR detectors, loud speakers and acoustic absorbent material.

Manufactured item which varies by content and manufacturer sizes and weights available in catalogues.

Manifold

Complete pipework flow and return manifold assembly usually connecting a series of plant such as boilers, chillers or heating/cooling coils, incorporating all valves and pipework components such as controls, and often pre-wired. Also called a pipe rack.

Size varies depending on application.

Mass Customisation

The benefits of mass production are creatively combined with systems that offer greater choice for the individual customer, improved control of the total construction process, and flexibility of assembly options.

Medical Gas (MedGas)

Specialist gases such as oxygen, nitrogen, helium, carbon dioxide, entonox and the like used in hospitals, research laboratories and manufacturing facilities usually in brazed copper pipelines. Specialist sub assemblies such as operating theatre pendants, bed head trunking Area Valve Shutoff Units (AVSU) and VIE plant. along with pipework on multi service modules.

Refer to specialist for weights of each configuration.

Module

These terms would imply a level of modular coordination (see Modular Co-ordination). More commonly, however, they refer to volumetric building modules where the units form the structure of the building as well as enclosing usable space. The terms are also sometimes used to describe room modules, which do not incorporate their own superstructure. They are particularly popular for hotels and student residences due to the economies of scale available from many similar sized modules and the particular benefit of reduced site construction time.

Modular Co-ordination

The discipline of designing buildings and structures using a specific module (for example 100 mm) where all the elements and components are described as multiples of the module.

Modular (Electrical) Wiring

A preassembled electrical cabling system, using pre-terminated electrical cables usually made up into looms or wiring harnesses to provide the electrical distribution system for all mains small power, lighting and controls (sometimes called Wiring Looms). Connectors in the field are referred to as an MDB (Modular Distribution Board) and a home run cable links from the MDB to the Distribution Board. Cables vary by application but typically are 4mm sq conductors in 20mm diameter armoured conduit or LSOH flex cable.

Multi-Purpose Riser

Multiple service vertical distribution module, usually constructed from hot rolled or hollow section primed or galvanised mild steel and incorporating appropriate building services which may or may not be lagged (insulated). These modules can be connected offsite, but are often transported in 3 floors typically 12m maximum 16m lengths 3.5m x 3.5m to avoid transportation problems.

Modules can carry combined mechanical and electrical services but most manufacturers specialise in one or the other. The majority of the electrical risers are manufactured using a mesh or ladder system to allow easy distribution at floor levels in various directions. These systems are often bespoke in design and while the base structure may offer a level of standardisation the dimensions and carrying capacity will vary from between projects. Maximum weight dependant on contents but 4 to 8 tonnes is the usual range.

Non-Volumetric preassembly

Items that are preassembled, but “non-volumetric” in that they do not enclose usable space.

Offsite Construction (OSC)/ Offsite Manufacturing (OSM) / Offsite Production (OSP)

Largely interchangeable terms referring to the part of the construction process that is carried out away from the building site. This can be in a factory or sometimes in specially created temporary production facilities close to the construction site (or field/flying factories). Common alternative spellings for offsite are off-site or off site.

Packaged Plant

A generic term describing one or more items of mechanical and/or electrical plant that are combined (packaged) in the factory to form a transportable unit. This can be as a single manufactured item such as an Air Cooled Chiller or a wider package from different manufacturers bringing together sub assemblies at a assembly plant including elements such as the plant items, pipework, wiring controls and the like. Sizes and weights vary by manufacturer and are available from catalogues.

PAM

Preassembled module.

Plant Room Module (preassembled)

Packaged or skid-mounted preassembled plant rooms prefinished in the factory, ready for direct connection to mains services onsite. Can include complete plant room areas including AHUs, fans, chillers, boilers, pumps and pressurisation units, together with elements of the building envelope. Typical sizes 16m x 3.5m x 3.5m x 25 Tonnes, roof plantrooms are often lighter due to crane capacity available at this construction stage.

Pod

Prefabricated volumetric pod, fully factory finished internally complete with building services. Probably not completed externally, except for roof-mounted plantrooms which may include external cladding.

Types of pod include bathrooms, shower rooms, office washrooms, plant rooms, kitchens.

Applications for pods include commercial offices, public buildings, hotels, airports, sport stadiums, hospitals, universities and schools.

Pod framing or structure may be cold rolled Light Steel Frame (LSF) or hot Rolled Hollow Section (RHS) steel, timber frame, pre-cast concrete or GRP (mainly for smaller pods).

Floors are typically suspended timber or concrete, tiled or finished as appropriate. Ceilings and wall covering are typically plasterboard, except for GRP/pre-cast concrete where that is the pod build material, tiled or finished as appropriate. Occasionally pods may be delivered as flat-pack assemblies.

Pre-wired Distribution Board Assembly (Electrical)

A preassembled distribution board fully internally wired usually complete with female sockets to connect modular wiring, internal components such as Miniature Circuit Breakers (MCB) and surrounding containment on a Pan.

Pump module (skid mounted)

Supplies water for domestic, heating and chilled water solutions, incorporating all pumps, valves, pipework and accessories usually pre-insulated and can contain all electrical and control components on a common base frame.

Size and weights vary widely dependent on duty.

Risers (preassembled)

Preassembled electrical and/or mechanical vertical distribution modules designed either to be self-standing structures or fixed to walls.

Service Walls

Preassembled dry lined internal walls incorporating small bore pipework and electrical services such as controls and small power.

Skids

Transportable frames for carrying standardised preassembled products, mainly building services, for example pump skids, boiler skids etc. Term sometimes used as skid-mounted boiler etc. Larger sizes may include flooring and access provision, smaller sizes usually services from the perimeter. Smaller size units are often used in retrofit projects to allow access via existing door openings.

Skinny Module

An assembly of small diameter pipework, cable trays and associated fittings for both horizontal and vertical distribution. Usually self supporting or using a single rail support.

Stillage

See ATIF

Sub Assembly

An assembly of components brought together at either site or in a factory to form completed systems or volumetric assemblies.

Terminal Module

A module containing a room terminal unit eg a Fan Coil Unit complete with valves, controls, pipework ductwork wiring etc.

Sizes for a fan coil terminal module typically 1.8m x 4.2m x 500mm deep x 200kg weight.

Transit Tag, Tie, Bracket or Restraint

Temporary restraint of a component or section to prevent unwanted movement during transport, lifting or installation and is removed when the assembly is in its final location. A typical example might be the use of a cable tie to restrain a spring hanger, a removable bracket to support a pipe tee outside the module frame, or a strap to give stability during an aspect change during lifting from the delivery vehicle ie horizontal to vertical. It is good practice to ensure these are easily visible colour such as red , are easily removed and of low value or reusable if not. Removal checks are required as part of the site installation checklist.

Valve Assemblies (preassembled)

Valve assemblies prefabricated to individual specification, which reduce onsite installation time, site storage requirements and purchase orders. Some valve manufactures offer this as an additional service with sizes and weights available from catalogues.

Volumetric Unit

These terms are usually used in one of two different ways:

- to describe volumetric units that enclose usable space but are installed inside or on top of a building (ie pods)
- to describe volumetric units that enclose usable space and are joined together onsite to form the whole building without the need for any extra support structure.

Units may be manufactured from many different materials including, steel, concrete and timber, with smaller pod units also available in GRP. Units are invariably fully finished internally in the factory with external finishes, such as brickwork, applied onsite or external factory-finishes such as composite panelling. Larger volumes are sectionalised into transportable weights and sizes, typically 3.5m by 3.5m by 16m and 25 tonnes although these vary by manufacturer and project. There is no limit to the number of modules and with structural frames can be stacked over a number of storeys.

Wiring Loom

A preassembled collection of cables and connectors (sometimes called Modular Wiring).

Sizes and weights of all items are only indicative and will vary dependant on duty project and module content.

8.0 Bibliography

Useful websites

- Buildoffsite is an industry wide alliance of clients, developers, designers, contractors, manufacturers, suppliers, government, advisors and researchers that aims to promote greater uptake of offsite techniques by UK construction. They provide considerable information and publications on offsite approaches and equipment, together with numerous case studies.
  http://www.buildoffsite.com/
- The Construction Industry Council (CIC) is the representative forum for the professional bodies, research organisations and specialist business associations in the construction industry.
  http://cic.org.uk/
- Construction Industry Research and Information Association
  http://www.ciria.org/
- Constructing Excellence is cross-sector, cross-supply chain, member led organisation set up after both the Latham and Egan reports into the future of the construction industry and aims to improve industry performance in order to produce a better built environment.
  http://www.constructingexcellence.org.uk/
- A lot of useful information on reducing waste is given on the WRAP website (Waste and Resources Action Programme).
  http://www.wrap.org.uk/category/sector/construction
- Information on the IMMPREST tool.
  http://immprest.lboro.ac.uk/
- The Lean Construction Institute aims to reform the management of production in design, engineering and construction for capital facilities.
  http://www.leanconstruction.org/

Useful guidance

- Offsite housing review 2013, Construction Industry Council 2013
- Buildoffsite yearbooks 2012, 2013, 2014-15
- Offsite Construction – Sustainability Characteristics’ Buildoffsite June 2013
- Improving M&E site productivity (TN 14/97) BSRIA 1997
- Design Framework for Building Services (BG6/2014) 4th ed. BSRIA 2012
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  http://cic.org.uk/services/the-cic-scope-of-services.php
- Designing out waste: a design team guide for buildings, WRAP
- The Health and Safety at Work Act 1974 and subsidiary regulations
- The Construction (Design and Management) (CDM) Regulations 2007
- The Construction Products Regulations
- The Building Regulations – specifically the Approved Documents. Factories Act 1961
- Training support can be found via the Construction Industry Training Board (CITB) and Construction Skills which maintains the National Construction College, the National Skills Academy and supports apprentices. Information is also available from the Engineering Construction Industry Training Board (ECITB)
- Securing Engineering Construction Skills for the Future, ECITB 2008
  http://www.ecitb.org.uk/AboutECITB/SecuringEngineeringConstructionSkillsForTheFuture/
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  http://www.b-es.org/files/3614/1405/5940/SEC_Group_BIM_updated_2014.pdf

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9.0 Standards

Offsite construction is a process – a means to the end aim of achieving a finished building/product. As such, just as with onsite construction, there are standards that apply to the finished product and to the various materials, components and products used for the construction, and there are standards and legislation that apply to the various work environments and safe systems of work. However, there are not really any standards that focus solely on offsite construction specifically.

The following provides an overview of some of the key standards and other schemes that are relevant. However, it is not, and cannot be, an exhaustive list in view of the numerous standards and best practice guidance that apply to construction and to manufacture.

9.1 CE Marking

The Construction Products Regulation lays down conditions for the placing of construction products on the market by establishing harmonised rules on how the performance of the products will enable the finished works to comply with the building requirements for construction works. These rules are found in the harmonised European standards for the appropriate construction product. The question is how does this system apply to offsite preassembled or packaged products such as pump or plant rooms?

Reviewing the list of harmonised European standards reveals that there are no such documents covering offsite prefabricated buildings which would indicate that there can be no CE marking of these types of buildings under the CPR. However, under the CPD, some companies have gone down the voluntary route for CE marking by applying for a European Technical Approval enabling them to apply the CE marking to their prefabricated building units or their metal frame or concrete frame building kits. This voluntary system will continue under the CPR with manufacturers being able to apply for a European Technical Assessment.

Under the CPR a construction works means buildings and civil engineering works and as such makes no distinction between those that are constructed on site and those constructed offsite. Either way, the construction products used have to be regulated either under the CPR if a harmonised standard exists or, if no harmonised European standard exists for that specific product, then under some other recognised means of proving fitness for purpose. Where a harmonised European standard exists then the use of CE marked products is mandatory.

9.2 The Buildoffsite Registration Scheme

The Buildoffsite Registration Scheme operated by the Lloyd's Register Group is a process based assessment scheme designed to benchmark offsite construction organisations against best practice in terms of competency, methodology and safety.

The scheme serves as the vehicle for the standardisation of best practice across the offsite industry in terms of the safe and competent delivery of a product or service which meets client requirements. The scheme covers the design, manufacture, construction and project management activities and focuses on the process of delivery as well as the delivered product.

Benefits of the scheme:

- **Offsite service providers:**
  - Demonstration of best practice in the offsite construction sector Listing on the Lloyd's Register web site promoting successful registration to the Buildoffsite Registration Scheme
  - Client organisations will actively use the Lloyd's Register web site buildoffsite Registration Scheme certificate to display at premises
  - Use of the Buildoffsite Registration Scheme approval mark for promotional purposes
  - Promotion of a safety culture within the registered organisation.

- **Benefits for client organisations:**
  - Assurance that the offsite industry supplier meets best practice in the safe and competent delivery of offsite services

The scheme takes ownership of accredited organisations performance and will investigate and respond rigorously to reports of poor performance.

The categories of accreditation are as follows:

- Design
- Manufacturing
- Construction
- Project management.

Source: http://www.buildoffsite.com/register.htm 30/07/13

9.3 BSI-OHSAS 18001:2007

BSI-OHSAS 18001[29] has been developed to provide a recognisable occupational health and safety management system standard against which management systems can be assessed and certified. It is to be used by organisations who want to implement, maintain and set up a management system to eliminate or minimise risk, for controlling occupational health and safety risks and improve performance in this area.

The criteria of this standard are equally applicable to companies providing traditional on site services installation and offsite solutions. However, offsite solutions have better working environment and safety both on site and at the factory, so manufacturers of offsite should find it easier and less costly to comply with the criteria of this standard.

[29] (BSI Technical Committee HS/1, 2007)

9.4 BS EN ISO 14001:2004

Supersedes BS EN ISO 14001:1996. Amendment dated 31 March 2010[30] – Implementation of ISO corrigendum July 2009

Specifies requirements for an environmental management system to enable an organisation to develop and implement a policy and objectives, which take into account legal requirements and other requirements to which the organisation subscribes, and information about significant environmental aspects. It applies to those environmental aspects that the organisation identifies as those which it can control and those which it can influence.

The criteria of this standard are equally applicable to companies providing traditional onsite services installation and offsite solutions. However offsite solutions have better working environments and safety both on site and at the factory, so manufacturers of offsite should find it easier and less costly to comply with the criteria of this standard.

9.5 BREEAM (2011)

BREEAM 2011[31] is an environmental assessment method and rating system for buildings. It uses measures of performance to evaluate a building's specification, design, construction and use. The measures include aspects related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes.

The following are the BREEAM categories under which buildings are assessed:

- Management (Man0_)
- Health and wellbeing (Hea0_)
- Energy (Ene0_)
- Transport (Tra0_)
- Water (Wat0_)
- Materials (Mat0_)
- Waste (Wst0_)
- Land use and ecology (LE0_)
- Pollution (Pol0_)

Offsite solutions have benefits in respect of a number of criteria against which BREEAM points are awarded, such as:

- Construction waste management (Wst01)
- Sustainable procurement (Man01)
- Responsible construction practices (Man02)
- Construction site impacts (Man03)
- Service life planning (Man05) * Use of responsibly sourced materials (Mat03)

Some of the issues BREEAM is concerned with need to be considered during the detailed design stages covered by RIBA Stage 4. With offsite solutions, the manufacturer may be part of the team at these stages, therefore these issues will have to be considered in collaboration between consulting engineers and offsite manufacturers.

[30] (BSI Technical Committee SES/1/1, 2009)
[31] (Barlow, 2013)

To achieve the relevant points, the service engineer and the offsite manufacturer need to consider the following issues:

- Sustainable procurement (Man01)
- Water quality – Building services water systems: minimising risk of contamination criterion (Hea04)
- External lighting (Ene03)
- Energy-efficient cold storage (Ene05)
- Energy-efficient transport systems (Ene06)
- Energy-efficient laboratory systems (Ene07)
- Energy-efficient equipment (Ene08)
- Water consumption (Wat01)
- Water monitoring (Wat02)
- Water leak detection and prevention (Wat03)
- Water-efficient equipment (Wat04)
- Insulation (Mat04)
- NOx emissions (Pol02)

9.6 PAS 1192-2:2013 / CPIc / Uniclass

Following Government requirement that all projects subject to public funding should implementing Building Information Modelling (BIM) by no later than 2016, more and more projects are adopting this way of work. Many offsite manufacturers and engineering consultants are amongst the early adopters, but those who are still to adopt should be preparing for it without delay.

PAS 1192-2:2013[32] sets out guidance for the collaborative adoption of BIM on projects and includes reference to key supporting documentation.

The Construction Project Information Committee (CPIc), formed from representatives of the major industry institutions, is responsible for providing best practice guidance on the content, form and preparation of construction production information (CPI), and making sure this best practice is disseminated throughout the UK construction industry.

It provides tools and guidance on all aspects of project information management including life cycle costing and sustainability, accessible via its website
http://www.cpic.org.uk

CPIc are working with the Government BIM task group to produce information and forms to help implement BIM throughout the construction industry.

CPIc members have been involved in the preparation of PAS 1192-2:2013 and the supporting documentation. This includes the CPIx BIM strategy templates and the development of a new classification structure – Uniclass 2 – specifically for use in BIM.

Uniclass2 is a system for the classification of construction information, to facilitate information exchanges and collaboration within the construction industry. Details can be found through the CPIc website above.

A publication by the NBS and the Construction Products Association titled “BIM for the terrified – a guide for manufacturers”[33] is also useful reading and includes further sources of reference on various aspects of BIM implementation.

[32] (BSI, 2013)
[33] (Gelder, Tebbit, Wiggett, & Mordue, 2013)

9.7 Plans of Work

RIBA Plans of Work, BSRIA Design Framework for Building Services and CIC Scope of Services

In support of the new processes developed for the implementation of Building Information Modelling (BIM) on projects, RIBA, BSRIA and the CIC have revised and aligned their respective plans of work (RIBA Plan of Work 2013[34], BSRIA BG6/12[35] and CIC Scope of Services – latest revision still to be published, but referred to in the PAS 1192-2:3013).

None of these identifies the process that can be best suited for the design and delivery of offsite solutions, although references to offsite are included in all of them.

Section 5 of this guide highlights the key issues corresponding to the equivalent stages in each of these documents.

9.8 ISO BS 10007:2003 Quality management systems

Guidelines for configuration management

This standard defines the terminology used in configuration management processes and provides guidance on the process. This process includes "configuration management planning, configuration identification, change control, configuration status accounting and configuration audit".

It builds upon traditional change control procedures used in the construction sector and is particularly relevant to managing the interfaces between onsite and offsite aspects of a project.

9.9 BS 5606:1990 Guide to accuracy in building

According to the BSI Web site, this standard "is intended to be applied to building rather than civil engineering works and aims to assist in the following:

- avoiding or resolving problems of inaccuracy or fit by assessing the dimensional needs of a design regarding tolerances, and then designing and specifying appropriately;
- assessing the likely achievement of tolerances specified for a particular project, and giving guidance on their realisation; and
- monitoring and controlling work during construction to ensure that it complies with specified accuracy". Source BSI Online Store 30/07/13

From an offsite perspective, it should be noted that the survey data that the standard is based upon is relatively old (from a prior standard published in 1978) and that suppliers' capabilities have improved over time. The project team should identify specific critical dimensions and the appropriate tolerances for achieving the best results when it comes to using offsite solutions.

[34] (RIBA, 2013)
[35] (Churcher, 2012)

9.10 BS EN 1090-1:2009, Steel and aluminium structures

+A1:2011 Execution of steel structures and aluminium structures. Requirements for conformity assessment of structural components

As with the case of BS 5606:1990 above, historically the more capable steel fabricators have been able to produce structures that are well inside the dimensional variability allowed by standards. The project team should identify specific critical dimensions and the appropriate tolerances for achieving the best results when it comes to using offsite solutions.

It is also worth noting that the deadline for the mandatory CE Marking of fabricated steelwork is 1st July 2014[36].

Also consider:

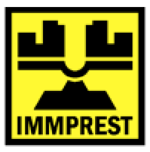
- BSRIA BG6
- Road Haulage Regulations
- Factory Standards
- Wiring Regulations

[36] Source: The Manufacturing Advisory Service, (MAS):

10.0 TOOLS

There are a number of tools that can be used to assist with the decision making process on whether and where to use offsite construction and to improve the efficiency of the process. The associated pictograms are shown in the sections of this guide where they are most relevant.

These include:

Pictogram	Tool	Suggested use at CIC project stages	Helps with	Good for	Not suitable for
	IMMPREST Benefits assessment	1,2,3,4,6	Seeing the holistic picture	Assessing both quantitative and subjective aspects	–
	Commercial Checklist	0,1,2,3,4	Getting the contracts to support the intended outcomes	Briefing commercial consultants	–
LEAN	Lean Construction Methods	2,3,4,5	Collaborative and efficient project delivery	Identifying value for a client, establishing demand-based flows of information and products, eliminating waste (non-value added)	–
	BIM & configuration management	0,1,2,3,4, 5,6,7	Design and construction process efficiency, collaborative working, stakeholder engagement, providing manufacturing information, meeting client information requirements	Developing fully integrated and coordinated designs. Supplying manufacturers with detailed requirements. Capturing handover information	–
	Design for Manufacture	0,1,2,3,4	Simplifying component designs to make them easier to manufacture	Reducing component and product costs	–
	Design for Assembly	0,1,2,3,4	Reducing the number of components that make up an assembly and making their assembly easy and mistake-proof	Reducing assembly costs	–
	Design for Logistics	2,3,4	Optimising how to move and lift potentially large assemblies and sub-assemblies with constrained sites	Ensuring safe and efficient delivery to and movements within the site	–
1st Run study	Prototyping and first-run studies	3,4	Proof of concepts and developing better ways of creating something	Finding problems before a design is finalised or work commences on site	Projects that do not involve innovation
MRP	Materials (or Manufacturing) Requirements Planning	4,5	High level procurement schedules and plant loading	More complex manufacturing systems	Very Lean manufacturing systems

ERP	Enterprise Resource Planning	0,1,2,3,4, 5,6,7	Running a complete (large) company	Integrating everything!	Any but very large companies who do not subscribe to the Lean philosophy
KANBAN	Kanban pull Scheduling	5	Creating demand pull based procurement methods	Keeping things simple and visual	–
6σ	Six Sigma	0,1,2,3,4, 5,6,7	Analysing and solving problems or deciding upon design options	Establishing a systematic and rigorous continuous improvement culture	Anyone who cannot handle statistics!

10.1 IMMPREST

Description

IMMPREST, the **I**nteractive **M**ethod for **M**easuring **P**reassembly and **ST**andardisation benefit in construction[37]. This considers a range of factors, including:

- Cost
- Time
- Quality
- Health and safety
- Site benefit
- Sustainability.

It compares costs with those of a traditional approach to construction.

Application

This can be used for most types of building project.

Benefits

It provides commercial and non-commercial team members with a structured way of making comparisons and decisions when it comes to comparing offsite approaches with traditional construction methods.

Source

Loughborough University. There is a small license fee payable for the Excel (TM Microsoft) based macros.

Use for

Benefits assessment.

Not suitable for

It may be limited in its application to civil engineering projects.

Example

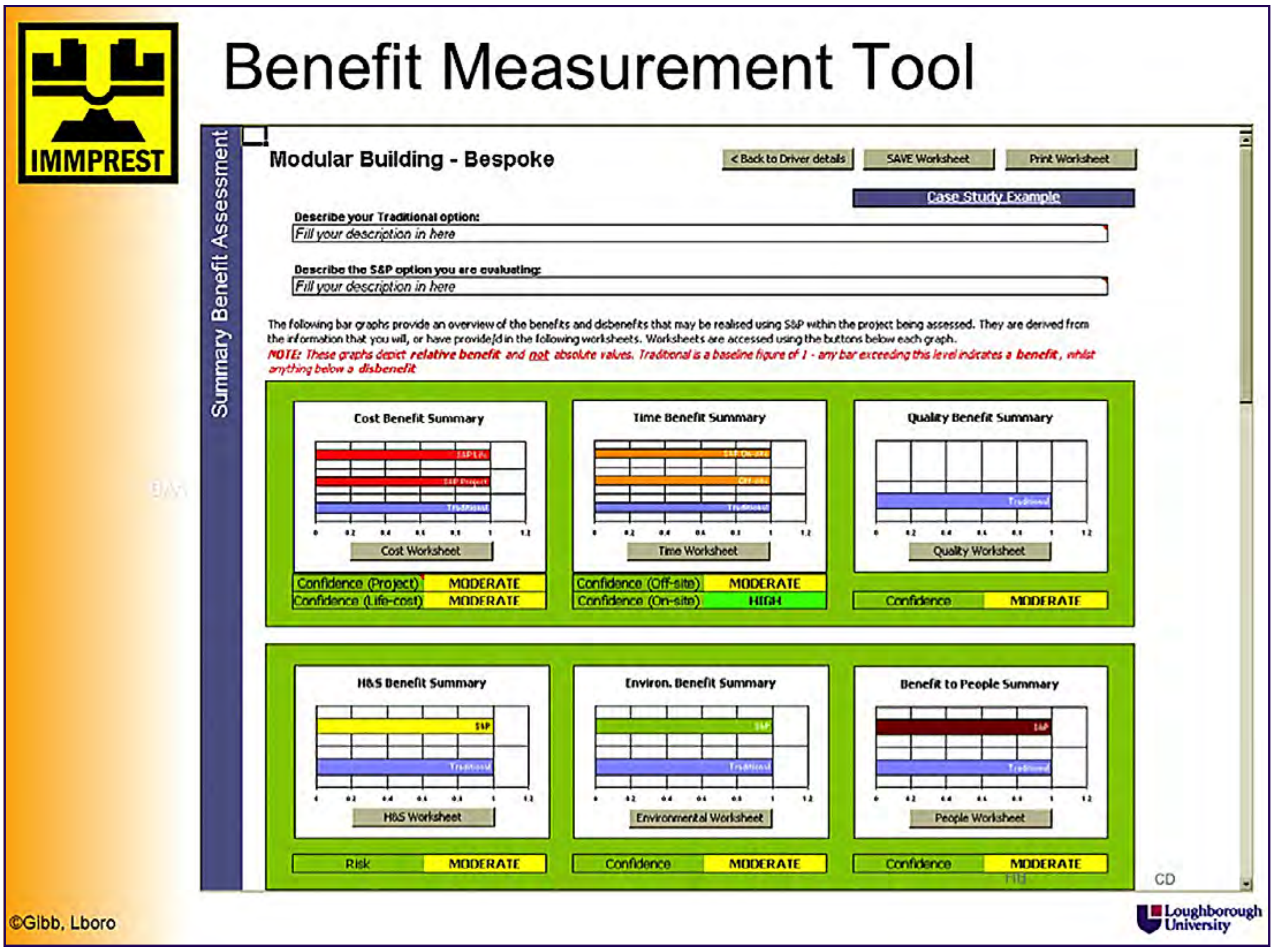
See case studies 6.2, 6.2 and 6.4 which were produced using IMMPREST.

Further information

The key to effective benefits assessment is taking a holistic approach to it. The former DTI funded research at Loughborough University developed an approach called IMMPREST.

[37] See www.immprest.com

The following figure, courtesy of Professor Gibb at Loughborough University provides a view of the results summary dash-board for IMMPREST:



10.2 Commercial Checklist

Description

This is a list of questions that are designed to help include the inclusion of contract clauses, which support the inclusion of offsite options and avoid others with unintended negative consequences.

Application

Use early in a project when contracts are being drafted, either for design services or for construction.

Benefits

It will ensure that the door is opened for offsite suppliers to bid for the project, which should unlock value in a number of ways.

Source

Created for this guide based upon learning with a major UK construction client.

Use for

Procurement planning.

Not suitable for

Using as contract terms.

Example

Commercial Checklist	
1	Does the form of contract encourage collaborative methods of working?
2	Does the contract require the use of 3D BIM and application of BSI PAS1192 parts 2, 3 and 4?
3	Do the payment terms link to delivery of the right thing at the specified quality and at the right time (not early or late)?
4	Does the contract ensure that suppliers are paid in a timely manner that reflects the profile of their own expenditure (as it would do if they were a supplier of labour and materials on site)?
5	Would the project benefit from single project insurance cover?
6	Does the contract encourage the early involvement of specialist sub-contractors in an advisory capacity?
7	Does the contract allow for a prototype or first run study?
8	Does the contract allow for the early procurement of project specific jigs and fixtures (including ATIFs)?
9	Does the contract allow for payment of early procurement of materials?
10	Does the contract allow for the holding of finished goods in a supplier's yard or 3rd party storage facility?
11	Does the contract recognise the need for a design freeze at the point which offsite elements are procured?
12	Does the contract require the application of formal configuration management to design changes and if so, from what point? (Ideally from the start of the project but the latest point being from the design freeze in 8 above).

Further information

The commercial model needs to support collaborative working between all parties to enable manufacture and assembly to proceed. The agreements need to match the requirements for continuous flow. A contract that requires all the trades to collaborate in the overall design of the facility, and overcomes liability issues is essential.

It especially needs to allow for early engagement of specialists before the design gets too fixed, and eradicates the benefit they can provide. The dichotomy to be addressed is keeping the commercial tension whilst getting early specialist input. Early delivery in a lean environment is as bad as late delivery therefore contracts should not have clauses that encourage this behaviour.

The correct contract terms will dramatically affect the size of the lay down and storage areas required and the amount of demurrage paid on vehicles. Stopping items from being made early will also reduce the number of finished assemblies requiring rework in the event of late appearing design mistakes or essential changes. It is also important to prevent intermediate companies, from withholding payment to their suppliers because of short term cash management activities. This will lead to supplies being delayed and the overall value stream being disrupted.

10.3 Lean Construction Methods

Description

The application of Lean Principles to the process of designing and building a facility.
The 5 Principles may be summarised as:

- **Value:** understanding what the client values
- **Value Stream:** how the value is created and waste eliminated
- **Flow:** a balanced flow of work
- **Pull:** demand created by the needs of the next customer in the process
- **Perfection:** the ultimate goal of continuous improvement.

Application

It is applicable to both offsite and onsite construction.

Benefits

Create a smoother work flow, with less waste, greater predictability, lower cost and a focus upon continuous improvement, delivering increased value to the client in terms of cost, time, quality and other aspects which represent value in that context.

Sources

The Lean Construction Institute, CIRIA, Constructing Excellence and numerous other sources. See: http://www.ciria.org/service/lean

Use for

Building or civil engineering projects.

Example

The case studies and advice throughout this guide involve aspects of Lean Construction.

Further information

Suggested reading: Build Lean, Transforming construction using Lean Thinking, Terry and Smith, CIRIA 2011.

10.4 BIM and Configuration Management

Description

Building Information Modeling (or Management) is a way of working that exploits our ability to create a digital model of a facility. There are numerous definitions of it, the most useful is defined in the UK Government's BIM Strategy. It is summarised in an illustration produced by Bew and Richards. It is reproduced below in figure 10.1.

The UK construction sector is mainly in the "Level 1 or 2" zones at the time of writing, with uptake growing rapidly.

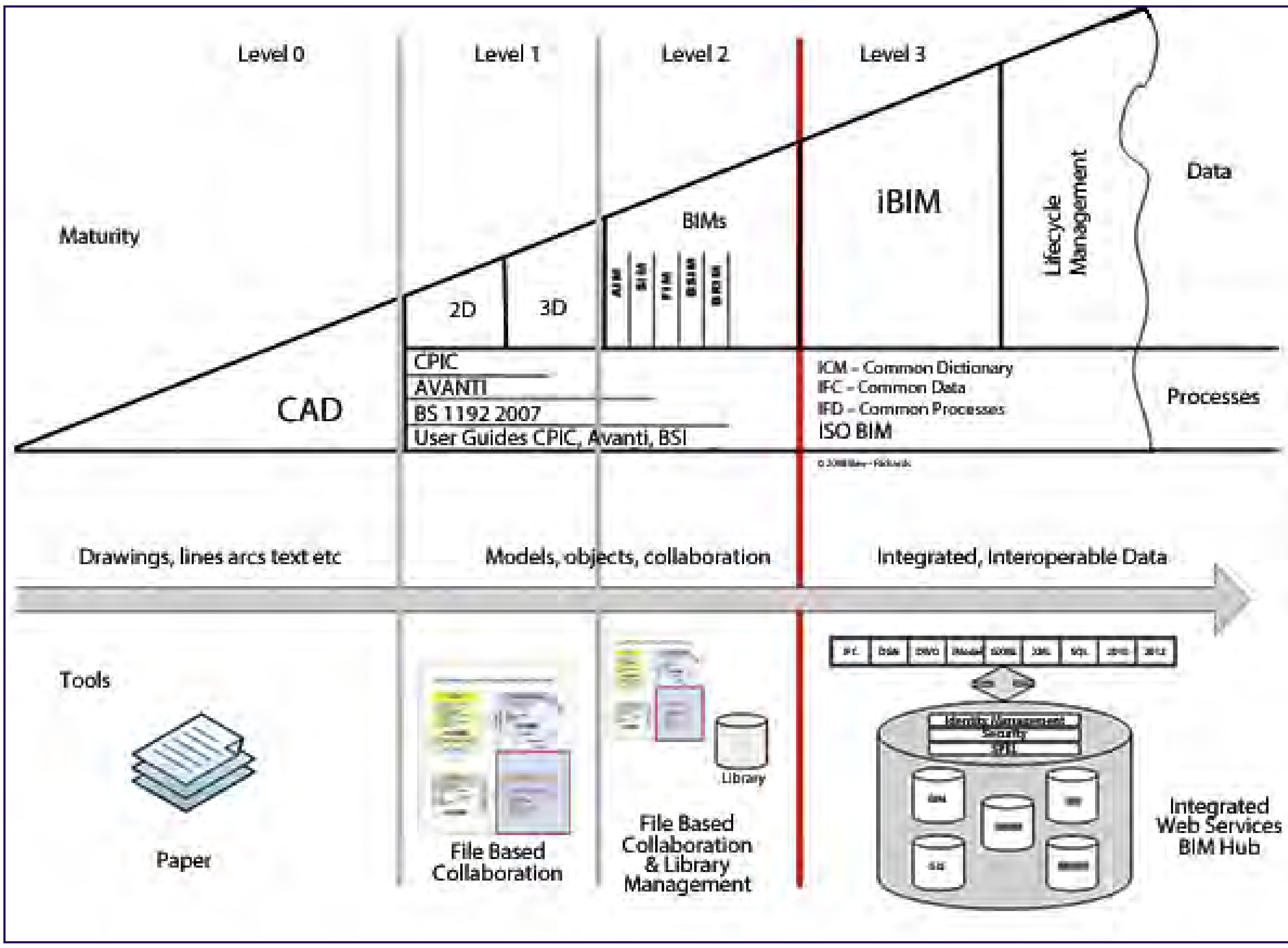


Figure 1: The Bew Richards BIM maturity model used by BSI and the UK Government.[38]

In the context of building and engineering services, this is generally implemented using specialist software that links into one or more of the major BIM software platforms.

The models are made up of "objects" which represent the components within a system. The objects contain both geometric, performance, maintenance and other related information. They are combined within the model to create the system

[38] http://www.bimtaskgroup.org/wp – content/uploads/2012/03/InvestorsReport – BIM.pdf

	A	B	C	D	E
1	Template Category	**Manual Isolation Valve**			
2	Template Version	v1			
3	Category Description	Manual Isolation Valve covers valve construction and types such as gate, ball, butterfly (ex. Life safety systems)			
4	Classification System	UniClass UniClass2 NRM OmniClass MasterClass CISfB			
5	Classification				
6	Suitability for Use				
7	Template Custodian				
8	Information Category	Parameter Name	Value	Units	Notes
9		Manufacturer Data			
10	Specifications	Manufacturer		Text	
11	Specifications	Manufacturer Website		URL	
12	Specifications	Product Range		Text	
13	Specifications	Product Model Number		Text	or code
14	Specifications	CE Approval		Text	number, yes, no
15	Specifications	Product Literature		URL	
16	Specifications	Features		Text	Free text to describe product
17		Construction Data			
18	Specifications	Application		Text	e.g. [illegible]
19	Specifications	Valve Mechanism		[illegible]	Endorsing Body
20	Specifications	Body Material		URL	Hyperlink to ETL webpage for product
21	Specifications	Valve Operation		Text	
22	Specifications	Shaft Material		Text	
23	Specifications	Stem Material			
24	Specifications	[illegible] Manual		URL	Hyperlink to Manufacturer O&M Data
25	Specifications	Daily		Text	Maintenance tasks or SFG20 codes
26	[illegible]/Asset Management	Weekly		Text	Maintenance tasks or SFG20 codes
73	Facilities/Asset Management	Monthly		Text	Maintenance tasks or SFG20 codes
74	Facilities/Asset Management	Quarterly		Text	Maintenance tasks or SFG20 codes
75	Facilities/Asset Management	6 Monthly		Text	Maintenance tasks or SFG20 codes
76	Facilities/Asset Management	Annually		Text	Maintenance tasks or SFG20 codes
77	Facilities/Asset Management	Bespoke Timeframe		Text	Maintenance tasks or SFG20 codes
78	Facilities/Asset Management	Maintenance Required 0-300hrs		Text	Maintenance tasks required during this time frame
79	Facilities/Asset Management	Maintenance Required 301-600hrs		Text	Maintenance tasks required during this time frame
80	Facilities/Asset Management	Maintenance Required 601-1000hrs		Text	Maintenance tasks required during this time frame
81	Facilities/Asset Management	Maintenance Required 1001-2000hrs		Text	Maintenance tasks required during this time frame
82	Facilities/Asset Management	Maintenance Required 2001-4000hrs		Text	Maintenance tasks required during this time frame
83	Facilities/Asset Management	Maintenance Required 40001-8000hrs		Text	Maintenance tasks required during this time frame
84	Facilities/Asset Management	Maintenance Required 8001-12000hrs		Text	Maintenance tasks required during this time frame
85	Facilities/Asset Management	Expected Life		Years	
86	Facilities/Asset Management	Warranty ID		Text	
87					
88	This spreadsheet is the property of CIBSE although it can be freely used in the ways described, and completed with data specific to particular products. It is important that the Categories and Parameters given on the form are not changed. It is also important that where units of measurement are defined on the form that these too are followed. Any comment or suggestion on their revision should be addressed to pdt@cibse.org				

Figure 2: A CIBSE Product Data Template (PDT) – to capture product general information.

The BIM objects, being defined in digital terms, can be processed to create information for manufacturing systems and to provide bills of materials for production requirements planning. There is a strong synergy with taking work offsite.

It also provides as means of issuing information about standard products and for marketing them.

BIM models permit simulations to be carried out on a proposed design. Examples of this in the building and engineering professions include environmental and acoustic performance.

3D BIM models simplify the task of coordinating building and engineering services, both with each other and, using software that can combine different types of model, with other aspects of the facility such as the structural design. In essence it permits the systems to be prototyped and optimised in a virtual world before procurement.

Good configuration management is a critical factor in the success of taking work offsite. This is because when the offsite elements are brought to site, the critical interfaces between the two need to work.

BS 10007 defines Configuration Management It concerns the ability to manage change and fully understand the relationships between the different configuration items that make up the overall product.

Examples in this context could be the dimensional tolerances for linkage points between adjoining modules, or the fixings to a structure or the floor to floor height that a services riser or escalator connects or the maximum height of a foundation that will support a services module.

BIM systems have powerful configuration management functions but they still need to be used effectively.

For example, if modules have already been ordered from an offsite facility, the consequences of making a change to the design will be significant. Any change to the site aspect of the interface (or vice versa) must not be changed without a full assessment of the consequences. Similarly, the personnel producing the on site elements, need to be made aware of the critical dimensions etc that are needed to make the overall construction process work.

Application

All construction projects

Benefits

In the context of building and engineering services, BIM enables better design coordination and performance simulation and evaluation. The major offsite suppliers in this sector have developed extensive BIM object libraries and are significant beneficiaries of BIM. Configuration management provides enhanced change impact assessment and management processes.

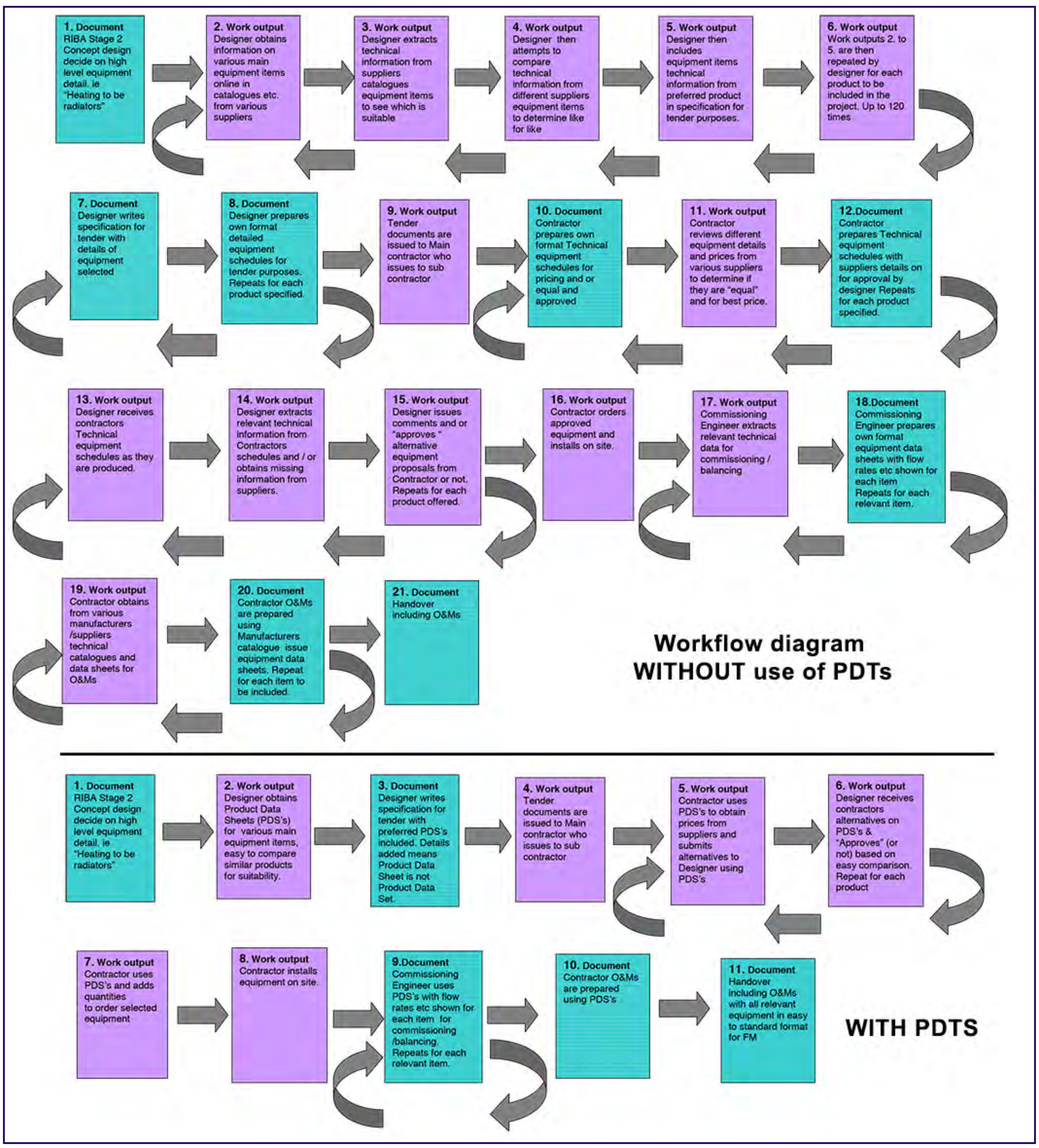


Figure 3: Workflow diagram following Mechanical and Electrical building services equipment through design installation and handover stages without / with use of Product Data Sheets; By: J T Beckett CEng MCIBSE

Just one note of caution, the above route map is for a traditional design-to-build contract where the design and installer teams integrate quite late in the process. With offsite manufacture the contractors would be on board much earlier and the designers would be part of their supply chain. So products would be agreed far earlier and the PDTs would come into play in a different way and place on the route map. Nonetheless, the above diagram does help indicate the differences in workflow between the two scenarios.

Source

BIM processes are well defined in BS PAS 1192-2 and referenced documents. Numerous companies provide proprietary software for implementing BIM systems.

Use for

All projects

Further information

A major free source of BIM related information can be obtained from http://www.bimtaskgroup.org

In addition, there is an SEC guide on BIM: **First steps to BIM competence : A Guide for Specialist Contractors**. SEC Group August 2014 http://www.thebesa.com/media/1169/guide-to-bim.pdf

10.5 Design for Manufacture

Description

The concept of design for efficient manufacture in its turn aims to simplify components so that they are easier to produce, for a lower cost. In some cases this may seem to offset the advantages of the above but in practice this has not been the case. Today, with wide spread use of computer controlled manufacturing processes, and simpler, controlled jointing methods (etc) the manufacture of slightly more complex components may not be much different to those with less demanding specifications. The key knowledge required by the designer is the current potential suppliers' manufacturing capabilities.

Application (Where do I use it / when do I use it?)

Project type:

Benefits (What will it help me do?)

Source

DfMA[39] (design for manufacture and assembly) was a process designed by numerous companies since the 1980s and there is plenty of material in the public domain.

Use for

The manufacture or procurement of components.

Not suitable for

Not all aspects are relevant for one off components.

Examples

- **A plug** – an example that most people can relate to is of domestic electrical plugs. In the 1970s they would have been assemblies with many parts. The housing was a two-part, hard plastic, the lid having an embedded threaded socket. Today, when attached to an appliance, the housing is a single element, moulded around the components within. The fuse holder is now accessible from outside (if there is one). Access to other components is no longer needed. The geometry of the casing is more complex but the molding method is simple once the right tooling has been designed and used.

- **The BAA corridor product** – the modular nature of the product family enabled the production of many variants on the same production line with a high degree of component standardisation and commonality across the different versions. By using the capabilities of the cladding supplier, the need for a structural steel frame to support the roof was eliminated.

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[39] (Note that the term DFMA is trademark of Boothroyd Dewhurst Inc in the USA).

Further information

Some key steps in the design for manufacture process in a construction context are:

Design for productivity

Checklist:

1. Determine the required site installation rate.
2. Assess the best way to divide up the design of the building / facility to optimise the off-site manufacturing process.
3. Design the layout of the off-site facility to ensure that work content at each work station, matches the required rate of output from the assembly facility. This is known as the “takt” time (rhythm or beat) and is determined by the customer’s requirement (i.e. site requirement).
4. Establish a “pull” mechanism from site to trigger assembly and ensure nothing is assembled unless this mechanism is activated. This trigger can take many forms from empty containers to an email.
5. Design the facility elements for logistics and productivity
6. Only ever assemble to the required installation sequence.
7. Control the material delivery & quality all the way down the supply chain.
8. Ensure the material receipt route & despatch route is defined and always clear.
9. Use in process inspection & acceptance.
10. Invest in dedicated jigs / tooling to locate preassembled modules quickly and easily.
11. Reduce the set up times from work piece to work piece.
12. Keep real time measurements of assembly efficiency, such as Overall Activity Effectiveness (OAE) to quickly indicate where problems are occurring (ref. CIRIA Lean KPIs Guide).
13. Use simple visual management techniques of material & tooling locations that can be easily understood by all personnel working in the area.
14. Employ formal problem solving to eradicate issues and prevent re-occurring stoppages.
15. Create visual method statements (or one point lessons – OPLs) for assembly that can be easily understood by (and are created with) the relevant personnel to ensure predictably and promote the training of those with lesser skills.

Design to be modular

This guide recommends using the six forms of modularity devised by B. Joseph Pine II in his book Mass Customisation, the New Frontier in Business Competition (**1993, Harvard Business School Press**). In any design two or more of these modularity types are combined to create an efficient solution that meets the client requirements for form, fit and function. This minimises the number of variants early in the design process, giving benefits to lead-tines, stock levels, repeatability of process (and therefore quality) but still allows customisation within pre-defined parameters. The six modularity types, with some examples, are:

1. Component sharing – the same pump used in different plant rooms.
2. Component swapping – different wall finishes on standard wall sections.
3. Cut to fit – mullions with standard jointing designs.
4. Mix – paint, concrete etc.
5. Bus – a standard framework that takes different M&E modules, or flooring section.
6. Sectional (this is like Lego) – lots of different components but with a common method of interfacing.

	**Design to make manufacture easy** This is really in the domain of the manufacturing experts and highlights the importance of having a procurement strategy that allows the early engagement of the manufacturers. The danger is that facility designers become carried away with Design for Assembly and don't take into account the complexity of the components that are the result. Difficult to form shapes, or components that are difficult to set during manufacture or which require multiple set ups will be avoided if the manufacturers advice is sought through-out the design process. If not the offsite benefit can be quickly lost
	**Use common parts and materials** Use configuration management in association with a defined part numbering system to control the number of parts. This is essentially promoting the benefit of designing once and using often resulting in; • reduction of stock levels • standardisation of handling and assembly operations • simplification of operator training • pre-tested systems • more predictable cost modelling • ability to use configuration management and part numbering system

10.6 Design for Assembly

Description

The concept of design for efficient assembly tends (amongst other things) to lead to the combination of components, reducing the overall number of them incorporated into the end product. Components may provide value in more than one conventional discipline.

Useful tools include:

Application (Where do I use it / when do I use it?)

Project type:

Benefits (What will it help me do?)

Source (Where do I find it? – Can I buy it / is it free?)

Use for

The development of early design advice and detailed design

Not suitable for

N/A.

Example

A panel that supports an assembly of pre-installed building services equipment may also be a structural element of the building. This may add some complexity to the component, as it may have to respect tighter dimensional tolerances and incorporate pre-drilled holes to receive fixings etc. Another example may be designing a structure to include flat soffits to facilitate the installation of frames carrying a range of services, cable trays etc. Whilst it may consequently add cost to one component, it may save substantially more in the overall context.

Further information

Some key steps in the design for manufacture process in a construction context are:

	Minimise and manage interfaces Checklist: 1. Identify all potential component or work package interfaces 2. Rationalise them to the optimum number required, re-using the same design where feasible 3. Pre-design interfaces 4. Describing the standard interface to be used with visual instructions on how to produce it 5. Use jigs or templates to achieve repeatability in assembly.

	**Simplify and reduce sub-assemblies and component parts** The description of this tool is based upon the work of Boothroyd, Dewhurst and Knight[40]. It requires three questions to be asked about any particular assembly to decide whether the number of parts can be reduced: 1. During operation of the facility does a part move relative to other parts? 2. Does the part have to be a different material from other parts? 3. Must the part be a separate entity from other parts? Designers then give consideration as to whether a part can be eliminated, combined with another part or can its function be performed another way. The benefits of simplification and variety reduction are: • Less likelihood of poor products • Reduction in fabrication (welding trades) and assembly costs • Easier procurement routes and better cash retention • Less area given over to stock • Shorter lead times • Less processing work The balance of consideration that the designers must make is that they do not inadvertently create a component that is more difficult to manufacture. However experience shows that reduction in a subassemblies component parts usually results in significant reductions in the part's manufacturing costs also.
	**Reduce assembly risks** A facilitated workshop is recommended, with the relevant skills, to produce a Process Failure Mode Effects Analysis (FMEA) is very beneficial in identifying the biggest assembly risk issues and generating expert thought on their mitigation. The mitigation may, and really should include the production of "visual method statements or "One Point Lessons" for use by assemblers. It will also direct the designers towards providing physical methods of mistake proofing the assembly to ensure right first time fit.

[40] Boothroyd, G., Dewhurst, P. and Knight, W., "Product Design for Manufacture and Assembly, 2nd Edition", Marcel Dekker, New York, 2002.

Make assembly easy

This guideline falls neatly into three elements

i. Site survey control and setting out

Accurate surveying and reliable benchmarks ensuring that tier 2 or 3 suppliers contribute to the overall build predictability by working off more reliable benchmarks and locating aids (such as pre-drilled holes) as the building evolves. Typically the “as-built” needs to be surveyed to an accuracy commensurate with the tolerances required in each areas.

ii. Specification of appropriate overall tolerances

Carrying out a tolerance analysis on the overall facility which identifies the critical dimensions in the design that are important for achieving alignment of major sub assemblies is useful to determine where certain, traditional tolerances would benefit from being tightened. For example when envelope suppliers provide secondary steel work or expensive adjustment bracketry to overcome the looser NSSS tolerances of the structural steelwork adds time and material costs. Therefore specifying a tighter structural steel tolerance may lead to an overall schedule reduction, not to mention a better fitting envelope.

iii. Physical & Geometric Features of the elements

When designing consider the following aspects.

Checklist:

1. Can the number of axis of assembly be reduced?
2. Parts should have features that will allow them to be easily inserted (eg chamfers)
3. Use easy methods of fastening such as: hand tools only, easy access to reach the fasteners, no excessive use of threads, minimising the number of different fixings and tools needed.
4. Proceed vertically and design parts to be positioned with the aid of gravity.
5. Do not over constrain the elements in a structure. Use its own self weight and geometry to locate it where possible.

List continued...

	6. Be aware of maximum lift size and weight due to crane size, access, lift height limitations. 7. Reduce the need for temporary bracing and support. 8. Aim to provide early weather tight environment to aid later installations 9. Avoid connections. Try to design elements so that their interfaces are at the same point and do not need an extra component to connect them. (This is assisted by the application of appropriate tolerances after critical tolerance analysis). 10. Reduce the number of parts in a product (see Tool 10.0 for a methodology of how to do this). 11. Under factory conditions items for assembly should be easily located before full engagement. (eg use of dowelled guides (one of four longer that the others) avoids error and damage. Tapered guides or splines achieve progressive fixity and accuracy in assembly.) 12. On-site, and with larger finished modules, assembly may require the same bolted final connections to be made for structural integrity, but assembly will involve greater risk due to the greater loads or forces (wind etc), and therefore may require / benefit from a jig / support to hold the modules in position for final connection to be made. This control would need to be in three dimensions. 13. The use of jigs or frames. It is easier to set out / line and level a two dimensional item, rather than to offer up several modules requiring adjustment / easing to achieve required equivalent accuracy. 14. Equally, use of common jigs and frames during factory assembly ensures on site accuracy when those elements are brought to site. 15. Investigate the use of material and process combinations that are perhaps less familiar but which could be more economic. Using a multi-experienced team prompts the investigation of material / process combinations that are not traditionally considered.
	**Design for easy handling** This is obvious but often overlooked as the offsite designs go through their iterations and improvements, but it is essential that what is produced is easy to handle once it gets to site. Checklist: 1. Are the lifting eyes easy to fit and positioned at the correct centre of gravity? 2. Are materials on pallets and which are not top heavy? 3. What are the best load sizes, i.e. not too small or too big and match the available lifting systems 4. Avoid sharpness, slipperiness and if its too flexible pre-assemble to rigid (possibly temporary) frames (see ATIF).

Use efficient methods of jointing

This is about reduction of variety, simplification of use and finding alternative new technologies that remove effort and improve fixity.

Checklist:

1. If using an over specified fastener reduces the variety and therefore the stock or the risk of not having it available when required, preserving the continuous flow of the overall facility assembly may well compensate for the component cost. (Remember that a week's burn rate saved on a project is likely to result in a greater cost saving than scrimping on a few component parts).
2. Fasteners that require special tooling are sometimes essential but should be avoided.
3. Fasteners that prevent parts being dropped during assembly (such as self tappers and captive nuts) will produce more predictable results.
4. Evaluate the many non-percussive fixings such adhesive tapes, which can provide very robust results.

10.7 Prototyping and First Run Studies

Description

Prototyping is the development of a pre-production version of a design. It may be part of a product or the whole thing. It may be at 1:1 scale or scaled down. It is usually based upon the design of an experiment, which is formed so as to determine whether the design will work as intended. Virtual prototyping is also possible using BIM software.

First run studies follow the first production run of a new product or part thereof and ensure that lessons learnt that could assist in producing it more effectively are captured and acted upon. They can also be used to obtain client or stakeholder approvals of designs.

Application

Where there are repeatable elements of a design or where there are high integrity requirements such as in safety critical elements. Project type: Large projects

Benefits

- Demonstrate that a design does what is intended.
- Help identify productivity and design improvements.
- Help achieve stakeholder approvals where needed.

Source

These are well established practices, documented in the public domain.

Use for

New complex assemblies

Not suitable for

Projects where there is no innovation.

Example

The case study of a water pumping station in Section 6.3 demonstrates a range of benefits achieved through the study of the initial product, as illustrated with respect to price in the table below:

Cost	Index	Benefit
Historic	100	
1st delivery	76	24%
2nd delivery	66	34%

At a conference, the programme director for a major new London tower stated that he had already built it 37 times in a BIM environment before starting on site.

Further information

This type of sub-project may be approached using the familiar Plan, Do Check, Act approach associated with many quality improvement activities.

10.8 MRP and ERP

Description

MRP: Materials (or manufacturing) requirements planning is a software assisted process that takes several sources of information and combines them to schedule what resources are required to manufacture.

Information inputs include:

- * Bills of materials
- Manufacturing routings (the operations, machines and manpower needed to make or assemble the components and products
- Inventories of raw materials, work in progress and finished goods
- Lead times for purchased items
- Customer orders and management requirements for output and production smoothing.

The outputs from the process include:

- Quantities and delivery dates required for purchased items
- Shop floor orders
- Labour requirement schedules
- Workshop orders for each manufacturing department or team.

ERP: Enterprise requirements planning is the big brother of MRP in that it integrates MRP into the wider management processes of the enterprise. Whereas MRP may be implemented for an individual factory in a group, ERP is designed to be implemented across the whole organisation.

Application

In manufacturing plants. Project type: It is not a tool for use in the project team.

Benefits

It is used to coordinate activities in factories and their supply chains.

Source

Major or specialised management consulting companies and the suppliers of software for implementing such systems.

Use for

Mainly complex factories or plants which are parts of larger groups that need homogenous systems across the business. Less suitable for: Small businesses that do not employ systems for ensuring automatic and accurate data collection on the shop floor.

Example

Most large and some smaller factories employ MRP or ERP type systems.

Further information

Both processes tend to “push” materials and other resources into the production system. Lean Principles focus on creating “pull” signals by which the client in the chain sends a message back to the prior supplier to furnish the required materials, components or sub-assemblies. Where the two approaches are used together, the “pull” aspects of MRP or ERP need to be limited to the overall scheduling activity, leaving simpler “pull” based systems to manage the detail on an hourly basis.

10.9 Kanban

Description

A just in time "pull" type materials requirements management system based upon physical or electronic tokens passed from the manufacturing cell to its internal or external supplier when it requires supplying. Developed by Toyota Corporation as part of its production control system.

Application

Production and inventory control. Project type: It can be used by projects to call in product from suppliers.

Benefits

It is a simple, visual system for controlling production systems and, over time, reducing work in progress and increasing stock turnover ratios.

Source

There are many Web sites that provide information on kanban systems. (Search for Kanban & Toyota).

Use for

Organising deliveries to sites, controlling materials flows in factories and ordering materials and components from supply chain members. Less suitable for: Manufacturing where each product is different, ie they do not repeat.

Example

A site may have limited put down space and so needs to pull deliveries of M&E modules in when conditions are right for their immediate installation. It could send a kanban type signal (email, fax or token) to the consolidation (or logistics) centre, which would make the delivery to the site and then send a similar signal back to the manufacturer to replenish the stock available for delivery to site.

Further information

A full description of kanban in construction was published by Glen Ballard in 2003. It can be found at: http://www.academia.edu/811557/Kanban_in_construction[41]

[41] Kanban in Construction, Ballard, Arbulu and Harper IGLC 2003

10.10 Six Sigma (TM Motorola)

Description

Six Sigma is a methodology and data centric tool kit for delivering business process and product improvement.

Application

Wherever there is a need for complex problem solving. Project type: Business improvement projects or where the design process needs to deliver very predictable performance of what is being designed.

Benefits

Help solve design challenges and business performance improvement problems.

Source

Six Sigma is covered comprehensively on both the Web and in publications. It is often linked to Lean as the two business improvement processes are largely complimentary.

Use for

Complex problem solving, the design of experiments and achieving right first time every time.

Not suitable for

People who do not want to engage with methods largely based upon statistics.

Example

There are many tools in the Six Sigma tool kit. A designer of a new type of cooling or heating system may find Taguchi's tool for the design of experiments helpful whilst many will be familiar with the Ishikawa "fish bone diagram" that often forms part of a structured approach to root cause problem solving.

Further information

GE is a company that uses Six Sigma extensively. Its Web site highlights the core concepts:

Critical to Quality:	Attributes most important to customer
Defect:	Failing to deliver what the customer wants
Process Capability:	What your process can deliver
Variation:	What the customer sees and feels
Stable Operation:	Ensuring consistent, predictable processes to improve what the customer sees and feels
Design for Six Sigma:	Designing to meet customer needs and process capability

Source: http://www.ge.com/en/company/companyinfo/quality/whatis.htm 30/07/13

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