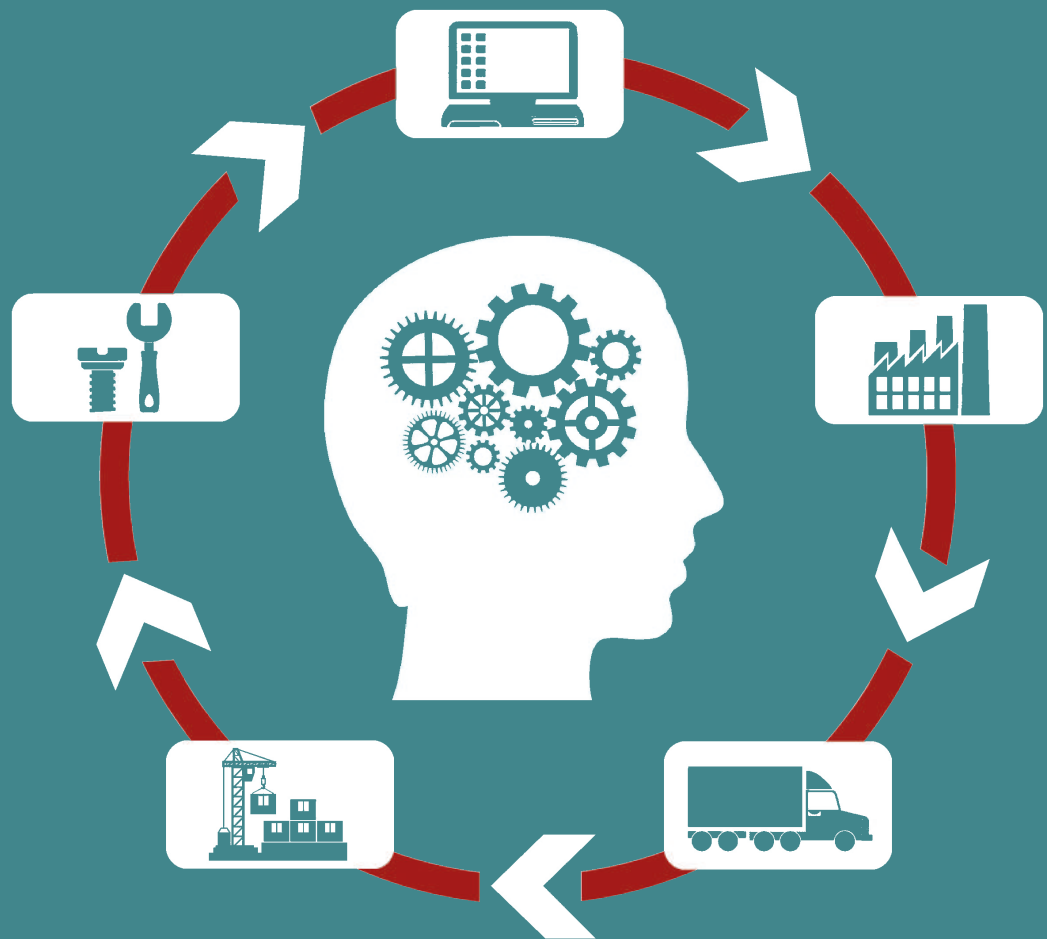


RIBA Plan of Work 2013

Designing for Manufacture and Assembly





RIBA
Plan of
Work
2013

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Foreword

The last wave of construction innovations embedded into the way we design were devised more than a century ago: steel frames (1890s), 'dry-lining' (1910s) and curtain walling (1910s). And today, although external walls may no longer be load bearing and might utilise cavity walls, they are still predominately built using 'wet trades', with one brick placed on top of another on site.

In recent years we have seen a number of initiatives nudging us towards the next major transformation in how we construct buildings. Driven by bodies such as BuildOffsite, these initiatives look at how we can maximise offsite fabrication and onsite assembly, minimising onsite construction. The tipping point, where we fundamentally change the culture around how we design for construction, has still to be reached.

Many observers of the built environment industry query why the construction industry is not more like the aerospace or car industries. Why have we not embraced lean thinking, kaizen or six sigma ways of driving radical changes in what we do? The reasons are, of course not simple. Planes and cars are assembled in giant factories with controlled environments. Buildings must be assembled where they rest. Splitting them down into smaller, modular components that can be assembled onsite is limited by transportation restrictions and other constraints. And, of course, every site can be different, particularly in our cities where most of our buildings reside. The briefs, demands and outcomes of our clients can differ from project to project. The historic context can create further constraints: those who control the interventions placed in these locations rightly impose stringent rules on the buildings that can be placed there.

However, in the same manner that historic context does not impede design creativity (the 2013 RIBA Stirling Prize was won by Astley Castle in Warwickshire, which was of a refurbishment of a Grade II* Listed Building. We should not be using the reasons set out above to impede innovation in the way we design for more effective construction outcomes. If there are construction methods that are faster, cheaper, safer and better for the environment we should be embracing them.

In reading the early drafts of this publication I realised that this publication was not about modular units or flat pack construction, it was about how construction could be transformed with Stage 5 of the RIBA Plan of Work considered as 'Assembly' rather than 'Construction'. I counsel every RIBA member to read this document and consider how they can use the methods set out here to help transform the way we design to make it faster, cheaper, safer and more environmentally friendly to build.

Jane Duncan

RIBA President, 2015–2017



Preface

The construction industry is reinventing itself, implementing significant changes in the way that projects are delivered. The government's 2025 productivity challenges are a core driver of change. The industry has already made progress towards the adoption of Building Information Modelling (BIM) by harnessing new digital technologies. Collaborative joint venture approaches to project delivery are now commonplace as client, contractor (and their supply chain) and design team relationships are re-examined and improved in order to deliver innovation.

Contractors are working with enlightened designers to innovate in many different ways. Skanska, Laing O'Rourke, Carillion and Costain are working to adopt lean thinking and offsite manufacturing processes. At Skanska this is called 'industrialisation'; Laing O'Rourke use the term harnessed for this publication: 'design for manufacture and assembly' (DfMA); Carillion have coined 'offsite & MMC (modern methods of construction)' and Costain use 'factory thinking'. Through the Offsite Management School we have agreed a common language, skill set and approach, which include five key elements: standardised design, design for maintenance, logistics, offsite manufacture and onsite assembly. It is about having an industrialisation mindset.

The Offsite Management School is helping subcontractors and their supply chains to learn new skills, but the School now needs the support and innovative thinking of design professions to drive further, more radical changes with even greater efficiencies.

As well as delivering projects faster, lowering costs and improving quality, the use of DfMA techniques will also result in better operational and in-use outcomes. There is no downside. By consistently embedding DfMA into your Concept Design at Stage 2, you will be able to drive the productivity gains necessary to deliver the UK Government's *Construction 2025* strategy and be part of a new, safer, more sustainable construction industry.

I hope this guide and the supporting FAQs, glossary and online resource library, provided by the Offsite Management School, will help introduce you to DfMA thinking, enabling you to harness it at the earliest possible project stage.

Rob Francis

Chair, Offsite Management School

Director, Industrialised Solutions, Skanska UK



Introduction

The global construction industry is worth £5 trillion and demand is growing rapidly. Independent research by KPMG shows that construction productivity has been flat since 1997, while in the UK generally, productivity has risen by 25% (figure 1).

UK productivity (1997 = 100)

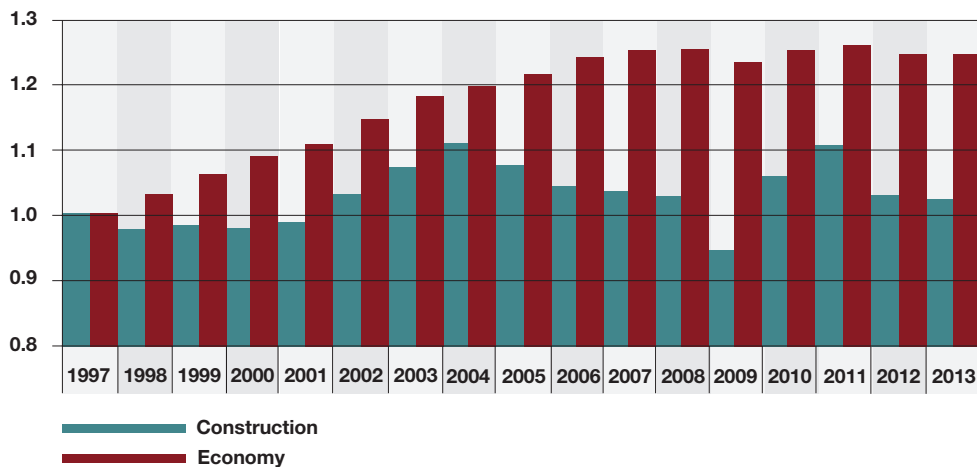


Figure 1: Productivity improvement over time

Source: Office for National Statistics

The United Nations predicts there will be a 33% increase in the world population by 2050, and that a similar proportion of the population will move to cities. This will drive demand for housing, infrastructure and commercial property. However, the world is using up resources at an unsustainable rate. According to WWF, we would need three planets of resources if everybody were to live Western European lifestyles, and six planets if we all lived like North

Americans. Forty-five per cent of the world's carbon emissions come from buildings, 90% of the world's hardwood goes to the construction sector and 50% of the world's landfill waste comes from construction. The statistics are clear. Construction is a major contributor to the depletion of global resources and as such can play a major role by devising solutions to minimise the use of resources, although a step change is needed to deliver the buildings we need in a more efficient and sustainable way.

33%
LOWER COSTS BY 2025

Buildings need to suit specific uses, users and locations. This has been a barrier to harnessing the benefits of offsite manufacture and mass production. Design for manufacture and assembly (DfMA) changes this. It enables the mass-customisation of solutions already used by other industries to become commonplace in the built environment industry. By harnessing new digital design processes and aligning them with offsite manufacturing facilities, new and profoundly different design processes will be generated. This will enable the design team to contribute to the UK Government's *Construction 2025* strategy ambitions of 50% faster delivery, 50% lower greenhouse gas emissions, 50% improvements in exports (reducing the trade gap) and 33% lower costs – all by 2025.

This publication examines how the design team can contribute to the process driving radical improvements in productivity.

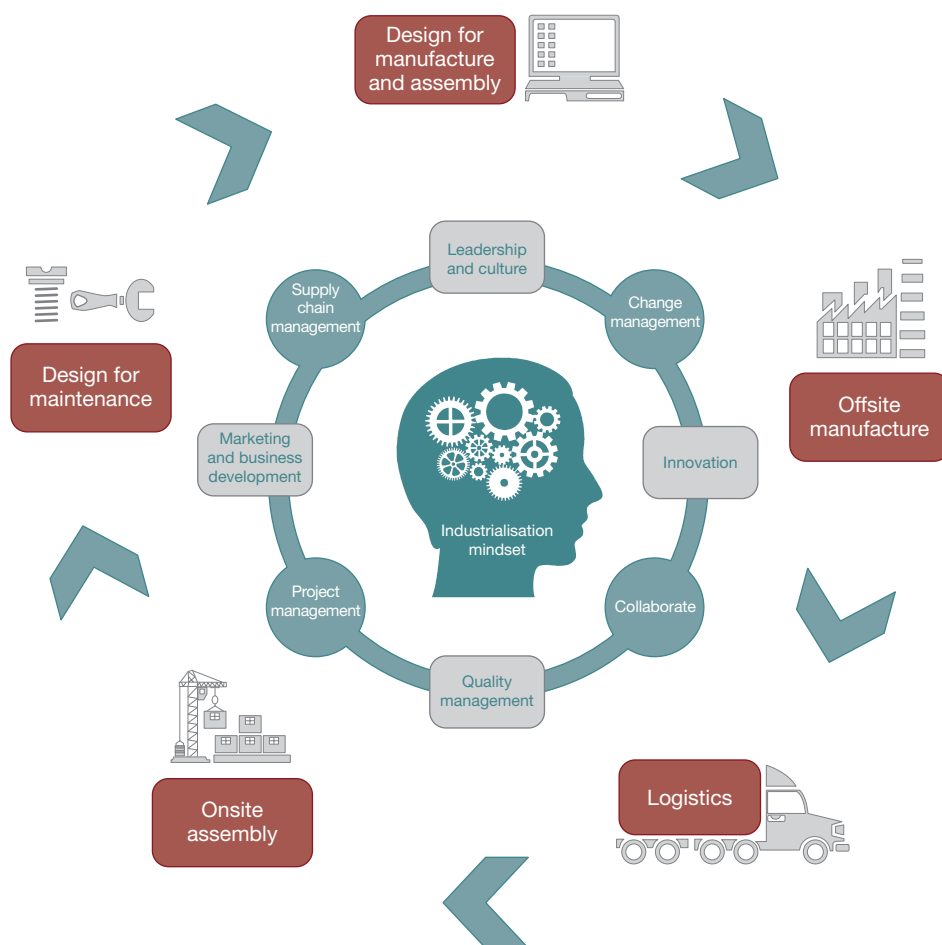


Figure 2: A DfMA mindset: through the stages of construction industrialisation



What is design for manufacture and assembly?

Design for manufacture and assembly (DfMA) is an approach that facilitates greater offsite manufacturing, thereby minimising onsite construction. It allows buildings to be constructed more quickly and safely, and more resource-efficiently and cost-effectively. DfMA does not impede design thinking or require any compromise in the quality of finishes or materials.

Levels of offsite DfMA

- ▶ **Component manufacture**
- ▶ **Sub-assembly**
- ▶ **Non-volumetric preassembly**
- ▶ **Volumetric preassembly**
- ▶ **Modular buildings**

Designing for manufacture is the process of designing in a manner that enables specialist subcontractors to manufacture significant elements of the design in a factory environment. Panelised cladding systems have been designed in this manner for many years. Designing for assembly considers how aspects of the design can be designed in a manner that minimises works on site and, in particular, in a way that avoids 'construction'. For example, a handrail system can be designed so that half landing lengths can be quickly installed into sockets pre-positioned in the stair structure, possibly incorporated into precast units.

DfMA harnesses a wide spectrum of tools and technologies. The underlying goal is to use design processes that help facilitate a collaborative approach along the whole value chain, embracing design teams, clients, contractors and offsite manufacturers. DfMA encompasses many techniques, including:

- Volumetric approaches, which create as much finished product as possible in the factory, minimising onsite labour completely.
- 'Flat pack' solutions, which output a kit of parts that can be quickly assembled on site.
- Prefabricated sub-assemblies (M&E services, for instance), which can be deployed in conjunction with more traditional elements, sometimes with similar effects to more 'complete' prefabricated systems.

In all these instances, assembly of elements may be undertaken remotely, or in a facility local to the site that has been established specifically for a project, perhaps to encourage and promote the use of local labour resources.

80%
CONSTRUCTION CAN BE OFFSITE

Adopting a DfMA approach does not mean that standard or manufactured elements need to be adopted. It may simply mean harnessing design rationalisation, materials optimisation, just-in-time delivery or logistics planning in order to achieve high rates of productivity on site. Seeking to find the most efficient way to deliver a project inevitably reduces the resources required (whether this is measured in carbon, cost or time) while increasing positive aspects (health and safety, quality and certainty). DfMA can be applied to one-off small-scale projects as well as to large-scale projects and frameworks.

Case study: Leadenhall Building

■ Architect:
Rogers Stirk Harbour + Partners

□ Contractor:
Laing O'Rourke



80% of the Leadenhall Building was constructed offsite using Laing O'Rourke's DfMA approach and offsite manufacturing capabilities.

The DfMA approach emphasised eliminating waste at source through efficient procurement, design, manufacturing and engineering methodologies. This approach increased the quality of materials and installation, reduced site waste, and reduced overall deliveries to site by 50%, avoiding air pollution and congestion.



Why is DfMA an essential current topic for designers?

Over recent years, DfMA has become more widely adopted in a number of construction sectors, including healthcare and hotels. Increasingly, clients, designers, contractors and operators are becoming convinced of the benefits of DfMA and are keen to apply the approach to more complex and bespoke buildings.

To be successful, DfMA requires the design team to think differently at Stage 2 Concept Design, in particular about the buildability aspects of their

designs. DfMA might not impact on a building's appearance, but if the design is to be suitable for developing for modern methods of construction during Stage 3 Developed Design and Stage 4 Technical Design, it is essential that DfMA is considered at Stage 2. DfMA is not just about efficient construction processes. When it is properly implemented it improves outcomes for costs, the environment, health and safety and time (these points are covered later in this publication). Fundamentally, DfMA requires the design team to shift their thinking away from traditional means of construction, to scenarios where buildings are assembled rather than constructed.

Building Information Modelling (BIM) is facilitating a culture of innovation and collaboration that assists the adoption of DfMA. The efforts made to create highly detailed, data-rich, fabrication-quality models, which bring together many design disciplines and the design work of manufacturers and specialist subcontractors, will continue to deliver better outcomes year on year. It is rapidly becoming the norm that a client expects to procure a project, design team or contractor that uses innovative digital design-to-construction processes. The number of 'construction innovation' questions in tender documents continues to increase along with their complexity. These allow innovators to continue to differentiate themselves from their competition, as BIM on its own becomes less of a differentiator.

Client perspective

"As a client, we are trying to improve how we serve customers, keep their bills low and keep our employees and supply chain safe. DfMA is an easy choice and we expect our design community to 'hard-wire' offsite thinking and standard products into designs so we can realise these benefits."

Kieran Brocklebank,

Head of Innovation, United Utilities



While the increasing body of published BIM case studies continues to demonstrate significant improvements in design-to-construction processes, these successes alone will not meet the targets set out in *Construction 2025*. Other innovations are required. CAD (computer-aided design) has not replaced architects or other members of the design team, and neither will BIM. Designers need to develop the collaborative behaviours required to deliver better and greater innovation, particularly at the boundaries between design, manufacturing and assembly and construction on site. Some clients, such as Highways England, are starting to require compliance with the BS 11000 collaborative working standard. This is ideally positioned to enable the benefits offered by BIM and DfMA to be realised.

Simply, those who consider DfMA as part of their BIM processes, who examine innovative ways of using digital tools to transition more effectively from design to construction and who adopt more collaborative ways of working, will secure more work.

82%
SKILLS SHORTAGE

From the contractor's perspective, a major benefit of DfMA is that it allows the labour required on a project to be redefined. The Chartered Institute of Building's *Skills Report 2013* indicates that there is a severe skills shortage in the UK construction industry: 82% of construction professionals surveyed for the report believe a skill shortage currently exists. While not mentioned in the report (published in April 2013), the issue will be exacerbated by the emergence of other resource-intensive major projects, including Thames Tideway, HS2, HS3, Crossrail, Crossrail 2, Hinkley Point C and Sizewell C, and by the fact that around 25% of people employed in the construction sector are expected to retire in the next five years.

By developing solutions that are 'assembled' rather than 'constructed', DfMA offers the prospect of using fewer people generally. Those who are required will have broader skill sets, providing a greater resource for the construction industry to draw from. DfMA also creates a more controlled and safer environment for those people to work in, away from traditional construction sites. Combined with the increased productivity generated by manufacturing in a factory, this approach eases the pressure created by the skills shortage.

Contractor perspective

"Construction industrialisation will allow the industry to tackle the skills shortage by significantly improving the efficiency of those who currently work on site, and through the increased use of modern, efficient factories we will attract and retain a more diverse range of talent into the industry."

Rob Francis

Director, Industrialised Solutions, Skanska UK
SKANSKA

Case study: Flying factories

■ Main Contractor:
Carillion

□ Specialist Contractor:
Skanska Rashleigh Weatherfoil

Modern 'flying factories' is a concept for offsite manufacturing and industrialisation of construction projects using temporary and flexible factories, while applying lean principles to the manufacturing process.



For Phase 1 of the Battersea Power Station site redevelopment, Skanska manufactured 540 utility cupboards (as pictured) in a flying factory, and constructed another 300 on site (the onsite construction was driven by site constraints, but provided good data on the comparison of the two techniques).

Compared with onsite fabrication and traditional methods of construction, the following savings were made:

- 44% reduction in cost.
- 73% reduction in quality/rework defects.
- 60% reduction in time.



What are the benefits of DfMA?

70%
REDUCTION IN LABOUR

DfMA might not influence the appearance of a building, but, if DfMA issues are carefully considered during the development of the Concept Design at Stage 2, it can significantly improve the construction outcomes. The benefits of DfMA include:

- 20%–60% reduction in construction programme time.
- Greater programme certainty.
- 20%–40% reduction in construction costs.
- 70%+ reduction in onsite labour, with subsequent improvements in health and safety.
- Reduced need for skilled labour on site.
- Better construction quality.
- Better environmental outcomes, including reduced waste.
- Fewer queries from site.

DfMA eliminates or reduces some of the problems typically associated with traditional construction.

- Advanced manufacturing firms routinely achieve productivity rates of 80%, but for onsite construction workers, productivity can drop to as low as 20% (source: *Totalflow Ltd*). Furthermore, site-based labour can cost up to twice as much as factory-based personnel. Employing lower cost, more productive workers has a significant impact on cost outcomes.
- Poor productivity and manpower shortages account for up to 37% of delays on site (source: *HM Government department capital programmes*). An 'offsite' approach reduces the total number of hours required on site, thereby reducing the risk of delays.
- Guidance on the NEC contracts estimates that in traditional 'construction', lack of design information accounts for 8% of delays on site. By manufacturing offsite, fewer decisions are required on site, substantially reducing the possibility of construction being delayed due to inadequate design information.
- According to Daniel Keeling, Chair of the Chartered Quality Institute's Cost of Quality Working Group, 'The UK construction industry is worth £100bn each year, and if you take just a conservative estimate of 1%–2% as the cost of defects, you are talking of around £1bn–£2bn in the UK. An American study has found that 5%–6% can be lost on defects.'

Case study: Circle Health Reading

■ Architect:
Bryden Wood

□ Contractor:
Vinci UK

The building system makes extensive use of design for manufacture, which reduced embodied energy, the construction programme (20% reduction) and cost (28% reduction).



Nearly 80% of the building was delivered using a standardised 'kit of parts', which included superstructure, MEP plant and distribution plus internal fit out. Bryden Wood used the project to develop a set of

processes, components and standard construction techniques that allow Circle to create high-quality, iconic, site-specific healthcare facilities across their roll-out while harnessing the benefits of DfMA.

By applying factory quality assurance procedures and factory testing, the amount of onsite commissioning and defect rectification is reduced by up to 70% (source: *BuildOffsite*).

- Safety continues to be the number one priority for the industry, but construction sites are still often hazardous environments for personnel. The CDM Regulations put greater onus on the principal designer, typically the lead designer, to eliminate foreseeable health and safety risks to anyone on a project. By developing a system that balances the use of offsite manufacturing and onsite assembly, the number of operatives on site reduces, facilitating safer ways of working. By assessing potential risks in a virtual world using 4D BIM, offsite manufacturing can be optimised, reducing site risks further. In particular, the avoidance of working at height can be a substantial safety benefit.

These benefits can be achieved by the following:

More efficient and collaborative working

- Reducing design rework and duplication of effort between the design team and the specialist subcontractors with design responsibility.
- Ensuring the optimum integration of design disciplines.
- Reducing and re-sequencing design time.

- Engaging the contractor's supply chain more effectively, drawing on expertise and innovation where it adds real value.

Choosing more efficient components and solutions

- Reducing waste by the efficient procurement of components, delivered through collaboration with contractors and the careful design and selection of components, materials and construction processes.

- Blending highly standardised, mass customisable and bespoke elements together with solutions that are finely tuned to suit the unique aspects of a particular site or client brief.
- Optimising the use of traditional, modular, 'flat pack' and system-build elements where they add the most value, e.g. to maximise offsite labour where appropriate and improve the efficiency of onsite assembly and construction.

Client perspective

"We see an ever increasing need for the use of offsite construction techniques, of which DfMA is an essential enabler. This shift will enable us to work with our partners to build quicker, safer, more sustainably and to a higher quality whilst gaining a greater predictability of both cost and programme."

Richard Elliott

Head of Construction, British Land



- Facilitating deconstruction and the future flexibility of buildings through the creation of standard components that can be readily adapted to future changes, including new building uses, and eventually disassembled more efficiently, moving towards a circular economy that is restorative by design.

Improving logistics

- Having fewer deliveries to site and fewer trades and activities on site.
- Reducing handling on site, resulting in reduced damage to components.

Improving quality

- Closer control of tolerances results in greater accuracy at component interfaces and better airtightness.
- The use of standardised solutions ensures that components and modules have been thoroughly tested before installation on site. In some instances components will already have benefited from feedback loops and continual improvement.
- Reducing onsite work also reduces opportunities for installer error.

What are the benefits of DfMA?

Reducing life-cycle costs

- By considering and understanding maintenance requirements early on and building these requirements into DfMA elements, life-cycle costs are reduced.

Improving environmental performance

- Research data from WRAP suggest that the use of volumetric construction has the potential to reduce onsite waste by 90%.
- Offsite manufacturing results in fewer traffic movements to and from site, reducing neighbourhood pollution and congestion by up to 20% (source: *BuildOffsite*). Onsite traffic, especially on larger sites, is also reduced significantly.
- Better control of dangerous substances (including solvents) is possible under factory conditions. There is also less risk of pollution to local watercourses.
- A reduced number of workers on site results in savings of up to 50% in the heating and lighting of temporary site accommodation (source: *BuildOffsite*).
- Standardised components enable the design of returnable containers, reducing onsite waste.

Case study: R.HOUSE

■ Architect:
Rural Design

□ Contractor:
James MacQueen Builders

An excellent example of how offsite techniques and DfMA can be utilised on a smaller residential scale.



Modular construction makes R.HOUSE a unique proposition. Factory construction is safer, cleaner and allows work in all weather. This ensures swift production and fixed pricing for design-led homes.

Outcomes included:

- 90% reduction in manufacturing waste.
- Reduced carbon emissions.
- Greatly reduced noise and disruption.
- Greatly improved build quality.
- Speedy erection of the house.

- Improved performance-in-use of environmental control systems (due to better assembly and factory-based commissioning) results in up to 30% reduction in CO₂ (source: *BuildOffsite*). The environmental saving for this improved performance is significant.
- Elimination of wet trades from site and the factory assembly processes reduce water consumption.

Improving safety

- Designing out high-risk onsite construction processes, such as hot works, working at height and live electrical testing.
- By limiting the number of hours operatives spend on site, adverse consequences (including falls and other injuries) can be reduced. BuildOffsite claims an 80% reduction in adverse site events.
- Reduced traffic movements to and from site lead to improved neighbourhood road safety – up to 20% reduction in road accidents within 0.5 km of sites (source: *BuildOffsite*).
- Planning ‘gain’ – the adoption of offsite methods can greatly assist neighbourhood consultation concerning perceived disturbance due to new works.

Environmental perspective

“The application of DfMA methodologies should allow us to drive efficiencies in the construction process. When implemented sensitively, DfMA has potential for eliminating waste at source, reducing the use of materials and ensuring a higher quality of construction that increases the energy performance of buildings, reducing the energy performance gap and thereby cutting CO₂ emissions.”

Julie Hirigoyen

CEO, UK Green Building Council





What are typical DfMA processes?

There are many ways of successfully harnessing DfMA processes, from including them as part of a traditional-build onsite project through to using advanced prefabrication techniques. It is possible to put an appropriate strategy into place on any project, and different practices and design teams can roll out and adopt DfMA processes incrementally, using increasingly sophisticated techniques as they become more familiar and comfortable with the approach.

The degree of 'granularity' of DfMA might also be dictated by the project requirements. The optimum DfMA strategy would harness the right scale and degree of standardisation to deliver a particular project. For some frameworks or multiple project roll-outs, site-wide standardisation of buildings might be beneficial; in other cases, standardisation at an apartment level might be more appropriate; and in certain instances, consideration at the component level may be sufficient.

The degree of granularity to be adopted will be influenced by the size and function of the components, from large-scale prefabricated assemblies down to connections or interfaces that simplify assembly on site.

A key part of any project is to define the DfMA strategy early in the design process. This will include a consideration of components manufactured off site, to determine which will add value without constraining creativity.

With more sophisticated DfMA approaches, all or a substantial proportion of the project can be designed and delivered using standardised prefabricated components (e.g. volumetric room-sized modules, prefabricated bathrooms, flat-packed wall, floor or ceiling panels), procured from the contractor's supply chain in large quantities and efficiently assembled on site.

At lower levels of sophistication, a project can be delivered traditionally but with consideration given to the logistics and management of the construction process, with the aim of creating 'factory like' conditions on site to counter traditional onsite productivity rates and reduce or eliminate waste material. Some prefabricated elements can be incorporated into a project that is primarily traditionally delivered, such as prefabricated M&E elements or prefabricated doorsets or windows.

As part of the design feedback loop (whereby experience gained from one project is used on the next), and to further reduce design time, designers can develop their own digital libraries of building elements. For example, the design of a stair core (stairs, risers, balustrading, finishes) can be standardised and fixed, incorporating improvements made following the conclusion of construction. Such standardised cores could be built traditionally, or might be delivered as a series of prefabricated elements (e.g. stair flights with finishes installed or handrail assemblies).

Case study: Library of Birmingham

■ Architect:
Mecanoo

□ Contractor:
Carillion

□ Specialist subcontractor:
Lindner Facades

In terms of bespoke facade unitised design and installation, the Library of Birmingham is a model example of what can be achieved when visionary architects work in close partnership with experienced envelope specialists to create an iconic and landmark building in a major city.



From the early conceptual stages, world-renowned architects Mecanoo worked together with main contractor Carillion and market-leading facade provider Lindner Facades. The unique and spectacular external aluminum circular frieze was

designed and fabricated off site by Lindner Facades, and installed in large sections to maintain the same factory-produced quality standards of the unitised curtain wall which it so eloquently veils.



What are the implications of DfMA processes?

Considering DfMA takes the design process further by requiring the design team not only to examine how best a building can be constructed (assembled), but also to consider throughout the design process how the components of the building can be manufactured most efficiently to aid the building process, hence the term 'design for manufacture and assembly'.

Adopting a DfMA approach does not always mean that standard or manufactured elements need to be adopted. It may simply mean harnessing design rationalisation, materials optimisation, just-in-time delivery or logistics planning in order to achieve high rates of productivity. Seeking to find the most efficient way of delivering a project inevitably reduces the resources required (whether this is measured in carbon, cost, time, waste or labour) while increasing positive aspects (health and safety, quality, certainty). DfMA can be applied to one-off or bespoke projects as well as to large-scale projects and frameworks.

Case study: London Bridge Station

■ Design Team:
WSP, Hyder and Grimshaw

□ Specialist Contractors:
Prater and Severfield

Leading specialist contractor Prater was responsible for the design, supply and installation of everything from the track-bed up on the prestigious London Bridge Station redevelopment.



The difficulties on this major project were in the complex geometry of the roofing system, the challenging environment and an incredibly tight programme for execution of the work.

Prater completely unitised the roofing package and pioneered a constructability prototype with its partner Severfield. Taking offsite manufacturing to a new level,

1,150 structural steel roof cassettes, each one bespoke, were craned in, complete with all the necessary M&E services. To mitigate any unnecessary risk from the earliest possible stages, the prototype was designed and installed at an airfield in Dalton and then dismantled and rebuilt – proving that Prater's innovative construction method would work once on site.

DfMA requires the way the building is designed to be considered throughout the RIBA Plan of Work stages, up to assembly at Stage 5 Construction. A robust Concept Design that has been developed with DfMA in mind will lead to a more efficient design at Stage 3 Developed Design and Stage 4 Technical Design. A successful and sustainable Construction Strategy, which has also been developed with DFMA in mind would:

- Consist of solutions that minimise risk and increase certainty of delivery.
- Include aspects of the design that have been standardised or repeated without stifling creativity and innovation.
- Seek to focus the time and effort of the design team on the 'bespoke' elements of a project, while optimising the use of BIM and standardisation to automate the production of repetitious information, which is often resource-intensive but adds little value.
- Comprise a streamlined delivery process that can more effectively create a high volume of design information, allowing creative skills to be deployed where they will be most valuable.
- Focus on reducing that proportion of the construction cost that adds little value but is related to risk, rework and waste during the construction process.

These points and the specific issues to consider at each RIBA stage are examined in greater detail in the next section.

Clients that undertake repeat projects, such as airports, hospitals, hotels and education buildings, have demonstrated that DfMA strategies can be developed at Stage 0 Strategic Definition and rolled out across multiple projects, thereby further increasing the value of DfMA.



What are the RIBA Plan of Work challenges?

DfMA is not new. If we are to successfully harness DfMA, it needs to be considered from the outset of a project, particularly as the industry transitions from traditional design-to-construction processes to digitally driven design-to-assembly ones. The way in which the building is designed must be constantly reviewed through the RIBA Plan of Work stages, up to assembly and construction at Stage 5. A Concept Design that has been developed with DfMA in mind during Stage 2 will be robust, leading to a more efficient design process at Stages 3 and 4.

The fold out on the inside rear cover presents a 'DfMA' Overlay which provides new task bars, in addition to the eight included in the RIBA Plan of Work 2013. They describe in greater detail how DfMA can successfully be considered at each of the eight RIBA Plan of Work stages. The DfMA task bars should be used in conjunction with the RIBA Plan of Work 2013: www.ribaplanofwork.com

The considerations at each RIBA Plan of Work stage might be as follows:

Stage 0

Strategic Definition



DfMA might not dictate whether a project goes ahead, but increasingly it is a core driver. In the hotel industry, for example, modular construction is becoming essential. Site appraisals may need to consider a given site's ability to accommodate modular construction, which in turn will affect the project's feasibility. Clients undertaking multiple projects with similar functional requirements may benefit from considering aspects of reuse from previous projects as part of Stage 0 and may appreciate a focus on creative continuous improvement.

Stage 1

Preparation and Brief



The Initial Project Brief should include a requirement for DfMA principles to be adopted, to encourage the design team to embrace the approach. In sectors where DfMA is commonplace, such as hotels, requirements for its use might be more emphatic, and it might even be mandated in the briefing documents. When assembling the design team the client should set out criteria that will help in assessing the design team's ability to deliver innovation using DfMA.

Stage 2

Concept Design



Many aspects of DfMA need to be ‘hard-baked’ into the design at Stage 2. For example, a building based on a column and grid approach is fundamentally different to one based on modular components. The lead designer should consider:

- What DfMA processes are currently used in the target sector (e.g. housing, healthcare).
- The availability and capabilities of known products or suppliers in the sector.
- The likely degree of repeatability and ways of improving this where possible (e.g. tweaking a handrail design to allow standard sections to be used throughout a building).
- The site and any logistical constraints that might limit DfMA approaches.
- The project scale and budget, and where DfMA might add value.
- The most appropriate DfMA solutions for the project.

In developing a DfMA strategy as part of the Construction Strategy, design team members should consider the benefits of DfMA (as listed on page 11) and how they might be applied to a specific project. For instance, on some sites, a reduction to the programme duration can mean less disruption to the wider community and therefore more favourable engagement during public consultation.

A successful and sustainable Stage 2 Construction Strategy, which has been developed with DfMA in mind, would:

- Incorporate solutions that minimise risk and increase certainty of delivery.
- Include aspects that have been standardised or repeated without stifling creativity.
- Seek to focus the time and effort of the design team on the ‘bespoke’ elements of a project, while optimising the use of BIM and standardisation to automate the production of repetitious information.
- Develop a streamlined delivery process that can more effectively create the required design information, allowing creative skills to be deployed where they will create greatest value.
- Focus on the reduction of construction costs by examining risk, programme duration (reducing preliminary stages), reduction in reworking and means of eliminating waste.

In summary, DfMA requires a Construction Strategy that is focused on more efficient ways of assembling buildings, rather than proceeding to Stage 3 with the traditional construction mindset.

Stage 3

Developed Design



Coordination of elements designed with prefabrication in mind, particularly within a federated BIM model, and the increased use of multi-functional components (such as the aircraft stand nodes at Heathrow T5) help to eliminate duplication and reduce costs. Early procurement of factory-manufactured prototypes can help the design team to hone designs before mass production commences, eliminating any details that are tricky to install on site and allowing the visual aspects to be fine tuned.

Stage 4

Technical Design



If the Construction Strategy properly considers DfMA at Stage 2 and the building components are progressively developed through Stage 3 and coordinated, Stage 4 should comprise the generation of design-intent information from the design team and the follow-on development of fabrication information (drawings or models) for approval. In situations where the design team, contractor and specialist subcontractors have worked together previously, short cuts may be feasible.

Case study: Empire State Building

■ Architect:
Shreve, Lamb and Harmon

□ Contractor:
The Starrett Brothers and Eken



To prove that the use of offsite techniques, standardisation and just-in-time logistics is not new, back in 1930 the Art Deco masterpiece that is the Empire State Building was built in just 13 months.

A standardised steel frame design, together with standardised logistics for bricks and tiles, to reduce logistics to site, and returnable containers for delivering floor packs enabled four and a half storeys to be completed every week and President Hoover to open the building on 1 May 1931.

Stage 5

Construction



In some situations, the site might be turned into a manufacturing or consolidation centre, where traditionally built elements (e.g. dry lining) are constructed more efficiently and productively. Pre-packed 'fit-out kits' can be delivered to site with everything required for an element of the works. For an apartment, this might include pre-cut boards and studs, tested and terminated 'plug and play' wiring looms, volumetric or flat-pack bathrooms and prefabricated services units (comprising boiler and water tank, underfloor heating manifold, electrical distribution board and whole-house ventilation unit).

Stage 6

Handover and Close Out



Crucial at Stage 6 is recording the 'As-constructed' Information for the building, including decisions made on site, allowing high-quality information to be available during the building's life for those who use and maintain it. This information can be diverse and might incorporate a wide range of manufacturer and DfMA information, including how the building might be disassembled at the end of Stage 7. It is essential that clients consider their project outcomes at Stage 1 and include them in the various professional services and building contracts.

Stage 7

In Use



Assessing a building's performance in 'real time' will increasingly become commonplace. This will allow the client and design team to receive Feedback on a building's performance, enabling the next project to be fully optimised, further improving its performance; a circular process, where Stage 7 to Stage 0 activity unlocks value. Maintenance issues related to the DfMA aspects can be collected as part of these exercises and fed back to the contractor and their supply chain.



What will the future look like?

We have unprecedented opportunities to harness technology to solve many of the problems of the built environment. Some of these technologies are already well understood, and are starting to be implemented. For example, digital modelling of the design process enables a deeper investigation and better optimisation of the design options for many subjects, such as functionality, energy performance, aesthetics, construction methods, maintenance and logistics. Further, more profound changes will occur, driven by delivery models that link design and onsite assembly more effectively. These include the following:

- **Advanced robotics:** Digital modelling will develop to facilitate process engineering, automation and the application of robotics to construction. Advances in robotics will enable DfMA processes that deliver mass customisation for the built environment. This will start with the transfer of technology from other sectors, then move increasingly towards the use of robots that are customised to suit the size and variety of construction components.
- **3D printing:** This technology will achieve widespread use due to its ability to produce an infinite variety of shapes at no additional cost.
- **Offsite manufacturing:** An increasing proportion of manufacturing will take place off site. In many instances this will be in temporary and flexible factories located close to the site.
- **The internet of things:** The future is a world where infrastructure is truly smart: where sensing technologies are embedded in infrastructure and the equipment it interacts with, often through management systems with wider functionality than we have seen in the past. Using tags and sensors, components will be tracked through all stages of production and in use. This will be combined with 'blockchain' technology to generate efficiencies in logistics and administering the chain of custody. The boundaries between buildings, infrastructure and centres of human activity will increasingly blur, as smart cities become a reality.
- **Wireless technology:** Data will be streamed wirelessly, collated, analysed and turned into actionable outputs. These actions will be carried out by either human operatives or automated control systems. In the production stages this will support continuous improvement in quality and efficiency. In the operation phase, sensors that monitor the condition of everything from structural components to rotating machinery will minimise failures and eliminate unnecessary checks and interventions.
- **User feedback loops:** We will increasingly see the introduction of user feedback loops. We will monitor the effects of the local environment on end users, enabling feedback into design and control. So, for example, we will be able to monitor the relationship between office design and productivity, hospital design and patient recovery, school design and learning.

- **Advanced materials:** In terms of materials, advances in aerogels promise a step change in insulation performance, which will lower costs and improve the sustainability of buildings. Allotrope carbon (graphene) has a strength-to-weight ratio 100 times greater than steel, and should be available for construction applications by 2035. Alkali-activated cementitious materials will increasingly be used to significantly reduce embedded carbon in concrete, and will provide other performance benefits, such as fire resistance, initially through their use in offsite precast components (following the publication of PAS 8820:2016).

With rapid change come threats and opportunities. Those gaining from the coming revolutions will be citizens, clients and the innovative organisations that offer new ideas and embrace change. The planet will gain from the application of renewable technologies and vastly more efficient use of materials. Workers willing to learn new skills will gain, including diverse groups not currently embraced by the industry. Under threat will be traditional trades, and supply chains.

It is difficult to predict exactly when these technologies will kick in, but it is likely to be sooner than we imagine. We can all look forward to an exciting future, in which the mantra ‘innovate or die’ has never been more pertinent. The result will be a radically improved habitat for humanity, and there will be good returns for the businesses that embrace the opportunities and work out how to deliver new ways of working.

Case study: 6 Bevis Marks

■ Architect:
Fletcher Priest, Adrian Priestman

□ Contractor:
Skanska

A Skanska-built office project in the City of London achieved an industry first by taking 3D printing out of the research labs and into a live project environment.



The 6 Bevis Marks project boasts 3D-printed cladding ‘shrouds’ for the top section of tree-like steel columns supporting an ETFE roof on the building’s roof terrace. The roof structure was an ideal candidate for 3D nylon printing, due to the complexity

and lack of repetition in the design. With eight different iterations, other types of manufacturing would have required eight different moulds, but eight unique cladding shrouds were produced direct from the CAD specifications.



Frequently asked questions

Will DfMA stifle our creativity?

DfMA is about transitioning to a more effective construction industry – one based more on assembly than on traditional construction methods – in a manner that reduces costs and is safer, faster, more environmentally friendly and improves quality. It is not about impeding or stifling design creativity, but it does require designers to consider and embrace more effective ways of transitioning from Stage 2 to Stage 5.

Does the DfMA supply chain exist?

The UK offsite supply chain is developing. Clients, architects, other design team members, contractors and subcontractors are working closely with manufacturers to help build the supply chain and its capacity to deal with the rise in demand, particularly as better design-to-construction processes are publicised and everyone in the built environment realises that DfMA results in more efficient, sustainable, safer and cheaper ways to create our built environment.

Will DfMA be more expensive?

No, but to harness the benefits of DfMA it is essential that the principles of DfMA are incorporated at Stage 2. A robust Concept Design that has been considered with DfMA in mind will generate a design that can be more efficiently developed for DfMA at Stages 3 and 4. Where efficient design-to-assembly processes are achieved, cost savings are realised. Attempting to 'retrofit' DfMA and offsite thinking into a project that is already at a later stage is unlikely to yield the outcomes set out in this publication.

How are business models changing?

Roger Bayliss, Senior Vice President Operational Efficiency at Skanska AB, has gone on record to say that the traditional business model of major UK contractors will not exist in ten years' time. What it will change into is not so clear, but if major contractors are embracing change it is clear that the design team and other stakeholders in the built environment value chain will need to adapt their own business models to respond to new ways of assembling and constructing buildings.

Can modular buildings be made to look less modular?

There are many ways of making modular building look less modular and to finish the junctions between modules, for example:

- Using features such as balconies, articulation in the facade (pilasters and ledges) or changes in material to hide the junctions between modules.
- Expressing junctions between modules positively, as part of the facade concept.
- Using large-format panels that span a number of bays horizontally or floors vertically to limit the number of joints.
- Using different module sizes.
- Post-applying flashings with preformed sections across joints as part of the facade articulation, or:
- For brickwork systems, post-applying brickwork 'stitching' across module joints, to give a finish that is indistinguishable from continuous brickwork.

As the use of modular construction becomes more commonplace, we are seeing designers use more and more creative ways to harness the method without the buildings appearing modular. As DfMA use increases and further ideas are revealed it is likely that, in the near future, DfMA buildings will be indistinguishable from traditionally constructed buildings.

Why do many modular schemes still use traditional cladding?

As alluded to in the previous question, one of the most difficult challenges in using modular construction is generating a building that does not look modular. In some locations, planners may have concerns regarding finishes and may insist on the use of traditional construction for facades, effectively limiting the use of modular construction to the 'interiors'. It is not uncommon for a modular building to be assembled in several days and for the facade to take several months to complete.

With time, as more and more buildings tackle this design challenge, more creativity will be mobilised. As a result, new and innovative solutions will emerge, demonstrating that modular construction does not impede design creativity or define the appearance of a building.

Does value engineering achieve the same results as DfMA?

No. Value engineering takes the value out of the design. Through DfMA, we are looking to add value.

Are there different levels of preassembly or offsite construction?

Yes. The following definitions have been used to describe different types or 'levels' of preassembly:

1. Component manufacture.
2. Sub-assembly.
3. Non-volumetric preassembly.
4. Volumetric preassembly.
5. Modular buildings.

Does offsite construction have project investor issues?

The BuildOffsite Property Assurance Scheme (BOPAS) incorporates assurance and insurance as means of mitigating many of the perceived risks to which the lending community and other key stakeholders, particularly in the residential market, are exposed in relation to DfMA techniques. Major clients may have longstanding relationships with their insurers and funders, which enable discussions about risk to take place in a wider context. DfMA often reduces risks (e.g. those associated with achieving the specified quality requirements, or health and safety and weather-related risks), but it may introduce new ones, which can be understood and mitigated using an approach such as failure mode and effect analysis (FMEA).



Glossary

This glossary describes commonly used terms for various offsite operations. It has been developed by the Offsite Management School, with the help of BuildOffsite, to aid understanding for those who wish to use offsite applications. More comprehensive definitions of terms are available in BuildOffsite's *Glossary of Terms* and the Building Engineering Services Association's *Offsite Guide* (see page 32).

BOPAS

The *BuildOffsite Property Assurance Scheme*, which incorporates assurance and insurance as a means of mitigating many of the perceived risks to which the lending community and other key stakeholders are exposed in relation to *offsite construction* systems and techniques.

BuildOffsite

An alliance of clients, developers, contractors, manufacturers, suppliers, government, advisers and researchers forming an industry-wide campaigning organisation that promotes greater use of offsite techniques by UK construction. See: buildoffsite.com

Collaborative design

DfMA requires collaborative interaction between designers, contractors, subcontractors (including specialist subcontractors), product suppliers and trades to encourage innovation in design-to-construction processes.

Component libraries

Many design team members are developing their own BIM libraries, to help them reuse information from one project to the next. Increasingly, these libraries are based on modules or assemblies that utilise DfMA processes. Manufacturers are also increasingly providing BIM objects to represent their products, either directly or through libraries. BIMobject, BIMstore and the (RIBA/NBS) National BIM Library (to name a few) provide objects, families and system files to use with major BIM and CAD software platforms. BIM software will also include a wide range of generic BIM objects. Component libraries are a core aspect of *continuous improvement processes* and *standardisation*.

Component manufacture

Small-scale manufactured items in everyday use, such as windows, are actually preassembled components, which in turn are installed on site.

Construction industrialisation

The development and improvement of construction work through the use of mechanisation and automation. The industrialisation of construction has several purposes: increase productivity, replace manual labour with machines, accelerate the pace of construction, put new projects into operation more quickly, reduce costs and improve quality.

Continuous improvement process (CIP)

A CIP is an ongoing effort to improve the quality of products, services or processes. CIP initiatives, particularly in manufacturing and *lean* construction processes, include: Quality First Attitude; Plan Do Check Act Cycle; 7 Tools of Quality, Audits and Inspections; and Poke Yoke (for mistake-proofing assembly operations).

Design for maintenance

Ensuring maintenance is factored into the design process to reduce whole-life cost. This should include the use of intelligent and smart (monitored and controllable) components.

Design for manufacture and assembly (DfMA)

DfMA takes many forms, but the common factor is the application of factory (or factory-like) conditions to construction projects.

Design for safety

Design professionals can influence construction safety by making better choices in the design and planning stages of a project; for example, by eliminating the need to work at height, or by eliminating the need for hot works on site, such as welding.

Digital engineering

Digital engineering refers to the digital interactions between design, construction, manufacturing and engineering, including Building Information Modelling (BIM): the digital modelling of a building or asset through design, construction and use. A core aspect of a *CIP* will be to improve digital engineering processes.

Field factory

A factory facility set up near to the construction site. A field factory might manufacture modules from scratch or might preassemble *flat pack* components before assembly on site. Field factories minimise the logistics associated with transporting modules and also enable larger modules to be manufactured due to the removal of transportation constraints. Field factories also allow the use of local or community labour sources, which can benefit the local economy of a project. Longer term, it is likely that field factories will increasingly involve the assembly of larger preassemblies as construction moves further and further towards fully assembled buildings.

Flat pack

Prefabricated elements or systems that are transported to site as 2D elements, rather than as *modular units*. This approach is used where *volumetric construction* options are not feasible due to transportation logistics.

Flying factory

See *Field factory*.

Hybrid building system

A combination of *volumetric construction* and *flat pack* systems, where the high-value areas (kitchen and bathroom) are typically formed from volumetric units and the rest of the structure formed from some form of framing system (also known as semi-volumetric).

Just-in-time (JIT) delivery

JIT logistics involve receiving raw materials, products and parts in the factory and then on site as they are needed, rather than days or even weeks before. This allows businesses to significantly cut inventory costs by having fewer unnecessary supplies on hand, and means they have far less material to store and handle. Where buffer stocks are considered necessary (e.g. as a result of a risk analysis), they are specified in terms of time periods linked to the assembly plan (e.g. one day of manufacturing).

Kit of parts

The term *kit of parts* is used to describe the notion of organising the individual parts of a building into

assemblies that are capable of being manufactured off site, and which are conceived in a way that allows them to be efficiently assembled on site. Developing a kit of parts concept in detail would involve considering standard easy-to-manufacture and assemble components and ensuring that they are sized for convenient handling or according to shipping and transportation constraints. The use of flying factories may allow the kit to contain larger components, although this will require early consideration.

Lean

The term *lean* is used in many ways, but it is essentially about removing any waste from a process. In this context, this would apply to any aspect of the design or construction processes. Increasingly, as design and construction become more efficient in their own right, lean principles will be applied to design-to-construction processes (Plan of Work Stages 2 to 4).

Material handling design

An approach to improving logistics and packaging of elements manufactured offsite, in order to make their transportation to the site and the onsite assembly process more efficient. For example, lifting points or positioning aids can be incorporated into components to aid assembly, or more effective use can be made of containerisation.

Modular units

Large modules used in *volumetric construction*. Units such as hotel rooms can be wholly constructed in the factory, as large modules that form the structure of the building as well as enclosing useable space. Units are fully finished internally in the factory, including many aspects of finishes, furnishings and equipment. Increasingly, external cladding, particularly glazing systems, are also installed in the factory, although in some instances finishes such as brickwork are applied on site (see page 27 in the section on *Frequently asked questions*).

Multi-skilled operatives

The use of modules with simple connections for services (e.g. water, electricity and telecoms) will require onsite operatives to have a wider range of skills but less depth of technical knowledge.

Non-volumetric preassembly

Preassembly of items that are non-volumetric: i.e. they do not enclose usable space. Includes cladding panels, building services ductwork, precast concrete bridge sections, structural steelwork trusses etc.

Offsite construction (OSC)

The part of the construction process that is carried out away from the building site. This can be in a factory or in a specially created temporary production facility close to the construction site (see *field factory*).

Offsite Management School

An online learning resource, free for industry to access, that focuses on the five stages of construction industrialisation: digital design; offsite manufacturing; logistics; onsite assembly; and best in class maintenance. See: offsiteschool.com

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, such as an electrical substation complete with cladding or an air-handling unit.

Pod

A prefabricated volumetric element, fully factory finished and internally complete with building services. Types of pod include bathrooms, shower rooms, office washrooms, plant rooms and kitchens. Pods use *volumetric construction* principles, but are smaller in size than *modular units* and are typically installed into traditional structural frames.

Process control and monitoring

The use of well-documented controls and procedures to ensure a repeatable process is used from design through to construction, enabling the production of consistent buildings from project to project.

Prefabricated building

See *modular units*.

Standardisation

The use of modules, assemblies, components, interfaces, methods or processes that are repeated through a project and from project to project. Standardisation benefits from the use of *continuous improvement processes*.

Sub-assemblies

Major building elements that are manufactured offsite, potentially using other offsite manufactured components. Examples include balustrading assemblies, facade cassette panels and preassembled M&E elements.

Supply chain

Everyone involved in the design, construction and, potentially, maintenance of a building, including the design team, contractor, subcontractors (including specialist subcontractors) and suppliers of materials and other aspects.

Supply chain integration (SCI)

SCI involves everyone in the *supply chain* working cooperatively and collaboratively, so that the collective effort effectively delivers the client's requirements and avoids unnecessary work. SCI is about adding value to design and construction processes, improving time, cost, quality, health and safety and other outcomes.

Volumetric construction

Volumetric construction uses large-scale *modular units* to construct a building. A building might be formed from one module or from many. Often, units such as bathrooms, plant rooms, lift shafts or services risers are installed within buildings, but do not, of themselves, form the building structure or fabric.



Where do I get help?

The Offsite Management School

www.offsiteschool.com/dfma

The RIBA has worked with the Offsite Management School to provide an online library of resources, containing e-learning modules, videos, case studies, web resources and a skills tool to enable any designer to benchmark their knowledge in DfMA. On the site you will find hundreds of resources classified at beginner, intermediate and advanced levels and also catalogued by media type. The School focuses on the five stages of the construction industrialisation process: digital design; offsite manufacturing; logistics; onsite assembly; and best in class maintenance. To support this process the School also provides learning resources on the eight enabling management competencies to help design practices build skills across their organisation.

OTHER HELPFUL RESOURCES

Building Engineering Services Association

An Offsite Guide for the Building and Engineering Services Sector available at:
www.besapublications.com

British Standards Institution

BS 11000-1:2010. Collaborative business relationships. A framework specification.
BS 11000-2:2011. Collaborative business relationships. Guide to implementing BS 11000-1.
PAS 8820:2016. Construction materials. Alkali-activated cementitious material and concrete specification.

BuildOffsite www.buildoffsite.com

BuildOffsite: Glossary of Terms 2013 available at: www.buildoffsite.com

CIRIA

The Offsite Project Toolkit available at: www.ciria.org

Constructing Excellence

<http://ccg.constructingexcellence.org.uk>

Loughborough University

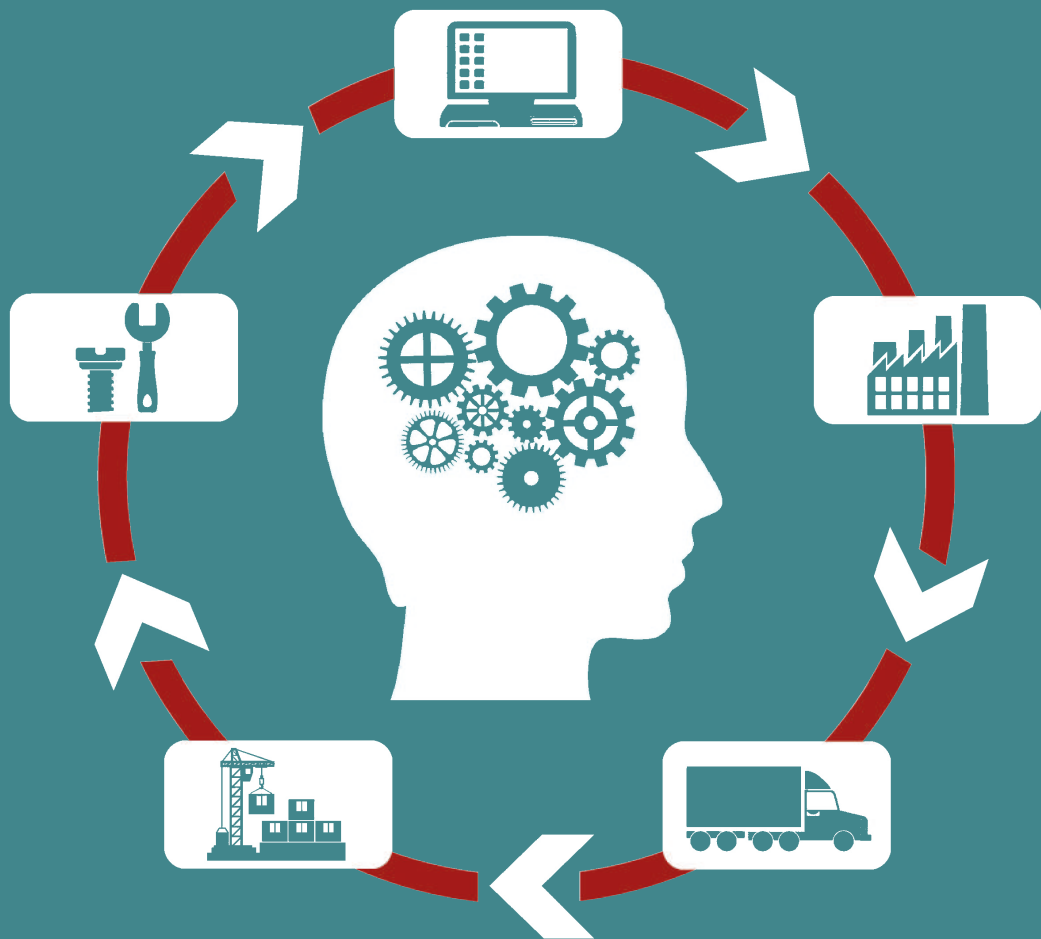
<https://offsite.lboro.ac.uk/proj-ciria.php>

Offsite Hub

www.offsitehub.co.uk

RIBA Plan of Work 2013

Designing for Manufacture and Assembly – task bars





RIBA
Plan of
Work
2013

RIBA

RIBA Plan of Work **Designing for Manufacture and Assembly overlay**

www.offsiteschool.com/DfMA

This Overlay to the RIBA Plan of Work 2013 includes additional task bars to support Designing for Manufacture and Assembly. It should be used in conjunction with the RIBA Plan of Work 2013: www.ribaplanofwork.com

Stages Tasks	0 Strategic Definition	1 Preparation and Brief	2 Concept Design	3 Developed Design	4 Technical Design	5 Construction	6 Handover and Close Out	7 In Use
Core Objectives from the RIBA Plan of Work	Identify client's Business Case and Strategic Brief and other core project requirements.	Develop Project Objectives , including Quality Objectives and Project Outcomes, Sustainability Aspirations, Project Budget , other parameters or constraints and develop Initial Project Brief . Undertake Feasibility Studies and review of Site Information .	Prepare Concept Design , including outline proposals for structural design, building services systems, outline specifications and preliminary Cost Information along with relevant Project Strategies in accordance with the Design Programme . Agree alterations to brief and issue Final Project Brief .	Prepare Developed Design , including coordinated and updated proposals for structural design, building services systems, outline specifications, Cost Information and Project Strategies in accordance with the Design Programme .	Prepare Technical Design in accordance with the Design Responsibility Matrix and Project Strategies to include all architectural, structural and building services information, specialist subcontractor design and specifications, in accordance with the Design Programme .	Offsite manufacturing and onsite Construction in accordance with the Construction Programme and resolution of Design Queries from site as they arise.	Handover of building and conclusion of the Building Contract .	Undertake In Use services in accordance with Schedule of Services .
DfMA Strategy	<p>Consider opportunities for applying DfMA across portfolios or programmes of projects.</p> <p>Consider how DfMA might impact on the Business Case or Strategic Brief.</p> <p>Consider whole life issues in the Strategic Brief including options for reuse or repurposing and recycling of components at the end of the building's life.</p> <p>Consider Research and Development that might assist Feasibility Studies or the Concept Design including intellectual property issues.</p>	<p>Initiate DfMA thinking and incorporate client requirements into the Initial Project Brief. This should include high-level targets for the extent of DfMA adoption and time/cost/waste savings against traditional benchmarks.</p> <p>Consider opportunities for 'repeatability', site/logistical constraints, Research and Development and early input required from specialist subcontractors.</p> <p>Consider best practice DfMA exemplars for comparable projects.</p> <p>Test the feasibility of high-level DfMA objectives included in the Initial Project Brief using the Site Information and Feasibility Studies.</p>	<p>Test initial Concept Design options against the DfMA aspirations set out in the Initial Project Brief. Identify opportunities for the greatest impact and initiate any Research and Development required to integrate DfMA into the Concept Design.</p> <p>Prepare the Construction Strategy considering high-level DfMA benefits including safety, productivity, quality and sustainability, considering topics such as eliminating scaffolding, wet or hot works, the delivery methodology and the suitability of proposed systems.</p> <p>Consider DfMA aspects in Risk Assessments and the Health and Safety and Maintenance and Operational Strategies.</p> <p>Ensure that the Cost Information takes account of the DfMA methodologies set out in the Construction Strategy.</p>	<p>Update the Construction Strategy taking into account DfMA opportunities appropriate to the Developed Design and coordination activities. Prepare a schedule of DfMA components and consider national (or other) standards appropriate for DfMA.</p> <p>Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces.</p> <p>Update Cost Information taking into account discussions with potential contractors, specialist subcontractors and suppliers.</p> <p>Update Risk Assessments and the Health and Safety and Maintenance and Operational Strategies taking into account DfMA considerations.</p>	<p>Develop the DfMA components more accurately considering the implications of the possible methods of manufacturing or fabrication. Develop the interfaces and specifications including structural, water/moisture/vapour penetration and acoustic issues.</p> <p>Update the Construction Strategy considering the lifting, handling and transportation strategy for each component and sub-assembly.</p> <p>Consider manufacturing and assembly risks in the updated Risk Assessment and Health and Safety Strategy.</p> <p>Develop a commissioning plan optimising the use of factory acceptance testing.</p>	<p>Update the Construction Strategy, including a logistics plan that ensures the right materials, plant and operatives are deployed in the right place at the right time.</p> <p>Commission the building progressively and capture 'As-Constructed' Information.</p> <p>Consider how DfMA impacts the Construction Programme.</p>	<p>Consider how to capture commissioning and 'As-Constructed' information in a manner that will assist the In Use stage including the potential disassembly of the building.</p>	<p>Consider any Feedback during the In Use stage necessary to inform future projects.</p> <p>Monitor the performance of standardised components including maintenance and replacement and provide Feedback.</p> <p>Monitor disassembly or potential reuse of materials during demolition at the end of the stage and provide Feedback.</p>
Suggested BIM Tasks for DfMA	<p>Analyse data from the existing building to identify key metrics for success.</p> <p>Gather cost and programme data from previous projects to set benchmarks.</p> <p>Consider establishing a BIM object library if components are going to be used across multiple projects.</p>	<p>Use BIM for the preparation of Feasibility Studies including data-rich 'placeholder' objects with limited geometry to assist in the preparation of Cost Information. Use BIM to test and optimise the Initial Project Brief.</p> <p>Include the Level of Development required at each stage when preparing the Design Responsibility Matrix. Consider the implications for professional services contracts and the Design Responsibility Matrix where a client is using their own BIM library, including intellectual property and professional indemnity insurance.</p>	<p>Develop the BIM model and components to the Level of Development set out in the Design Responsibility Matrix. Validate the model against the client's information requirements.</p> <p>Consider DfMA tolerances in the development of the BIM model.</p>	<p>Progress the BIM model and components to next Level of Development as set out in the Design Responsibility Matrix. Validate the model against the client's information requirements.</p> <p>Use digital technologies as part of coordination exercises.</p>	<p>Progress the BIM model and components to next Level of Development as set out in the Design Responsibility Matrix. Validate the model against the client's information requirements.</p> <p>Use 4D technologies to test and rehearse the sequencing set out in the Construction Strategy, including every aspect of manufacture, logistics and assembly before work starts on site.</p>	<p>Use BIM to train site operatives.</p> <p>Use digital technologies to track each step of the manufacturing, packing, logistics and delivery process.</p> <p>Consider recording the complete history and location of every component for Feedback, future use and learning.</p> <p>Link components to assembly manuals, method statements and quality records including identifying any aspects of the design which may be reused in the future.</p>	<p>Ensure any relevant documentation relating to DfMA components is linked to BIM components for Feedback, including lessons learned and potential repurposing.</p>	<p>Consider configuration management techniques to maintain an up-to-date record (BIM model) of the building.</p>
Suggested Procurement Tasks for DfMA	<p>Feedback – Ensure lessons learned from previous projects have been incorporated.</p> <p>Consider how DfMA impacts on the assembly of the project team including how the project team will achieve a collaborative approach and how innovation can be incentivised.</p>	<p>Consider how to emphasise the importance of DfMA in the Initial Project Brief when assembling the project team and developing the Procurement Strategy, including how to select design team members with DfMA experience.</p> <p>Ensure that any tender information encourages the behaviours required for effective collaboration and the experience needed to identify early DfMA opportunities.</p>	<p>Update the Procurement Strategy and hold discussions with contractors and specialist subcontractors relevant to the procurement route to test DfMA objectives set out in the Concept Design including the Construction Strategy.</p> <p>Consider the appropriateness of early contractor involvement (ECI).</p>	<p>Hold further discussions with contractors and specialist subcontractors relevant to the procurement route to test DfMA components and coordination exercises set out in the Developed Design including the updated Construction Strategy.</p>		<p>Capture Feedback including lessons learned from site installation to inform the Procurement Strategy of future projects.</p>	<p>Ensure that 'As-Constructed' information relating to DfMA elements has been delivered including Feedback on information to be incorporated into the client's in-house BIM object library.</p> <p>Provide Feedback on the capability and performance of specialist subcontractors who delivered DfMA aspects.</p>	

