DfMA Overlay to the RIBA Plan of Work

MAINSTREAMING DESIGN FOR MANUFACTURE AND ASSEMBLY IN CONSTRUCTION

2nd Edition, 2021

RIBA
Plan of Work

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Published by RIBA with the generous support of

Credits and acknowledgements
The authors would like to thank the many individuals who generously contributed their time and hard-won experience and expertise to ensure that this guide is truly representative of the views, needs and wishes of all parts of the UK construction sector.

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Published by RIBA, 66 Portland Place, London, W1B 1AD.

Front cover image Ten Degrees, 100a George Street, Croydon, currently the world's tallest Category 1 modular building © HTA Design, Tide Construction and Vision Modular Systems

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Foreword

It is abundantly clear that business as usual in building design and construction will not adequately address the pressing global challenges of the climate emergency and a growing population, or even the sectoral challenges of labour shortages and, as we know from the Grenfell Tower fire, a poor safety record.

Fortunately, there is hope. The great technological advances of the twenty-first century – in computer processing, materials science, manufacturing and data analysis – have helped humans to see the interconnectedness of everything, improving our ability to predict outcomes amid uncertainty and, importantly, giving us the tools to confront the challenges ahead.

Today, the sector has greater access to more relevant knowledge and technology than ever before in the history of building. It has allowed us to cherry-pick the knowledge and systems from the worlds of advanced manufacturing and digital technology to adapt the potential of design for manufacture and assembly (DfMA) and refine modern methods of construction (MMC).

This innovation in no way diminishes the complexity involved in getting from where we are now to where we need to be. While technical solutions already exist and evolve (and new technologies emerge), encouraging the whole industry to adopt them – as we must do for the future well-being of humankind – is a challenge.

The transformation is well and truly under way, however. Big commercial players are investing in factories and new processes, encouraged no doubt by the UK Government's presumption in favour of offsite manufacturing enshrined in the *Construction Playbook* and *Value Toolkit*.

The professional institutions are at the heart of this shift, most notably through the RIBA's DfMA Overlay to the Plan of Work. Five years on since the first edition, the state of the science and background context has changed to the point where a new edition is needed. RIBA is once again leading, with the generous support of experts representing a wide cross-section of the industry and our far-sighted sponsors.

This edition marks a tipping point, embedding DfMA as part of the default, everyday setting for everyone contributing to the design of the built environment. In doing so, we acknowledge the proven potential of DfMA solutions to produce not just good outcomes, but great architecture too, as the case studies presented here show.

Architects can be seen as the natural custodians of good design and have the potential to help lead in the adoption of DfMA. Not least as we understand that successful implementation lies in collaboration at the boundaries between traditional disciplines and in developing hybrid solutions that draw on a wide range of different bodies of knowledge. If we are to meet the challenges ahead, we must explore this territory, working together to do things differently. To help us, I commend this new Overlay as our guide.

Simon Allford
RIBA President and Executive Director,
Head of Design Studio, Allford Hall Monaghan Morris

Preface

The new DfMA Overlay to the RIBA Plan of Work and this accompanying report come at what increasingly looks like a seminal point in the construction industry's evolution. Despite numerous attempts over the years to respond to external market drivers and to reform and modernise, an overwhelming accumulation of factors that are set out in this report are now forcing the industry to think again about how it delivers.

I have always been very clear though that the process of delivering a different outcome starts at the beginning with the client and their advisory team. That is why the latest RIBA DfMA Overlay is such an important step forward. How clients and their teams set their projects up from Strategic Definition stage onwards has a massive impact on the success or otherwise of adopting manufacturing principles and effectively deploying the various modern methods of construction (MMC) that are starting to really take hold in the UK construction industry.

When I chaired the MHCLG MMC Working Group that developed the seven-category MMC Definition Framework back in 2019, it was always acknowledged that defining the physical types of MMC being used, from offsite to on-site approaches, was only part of the challenge. Alongside defining the building systems and technologies, there was a need to define the process by which you enabled the optimisation of MMC. That relies on the correct approach to client project management, from setting initial client requirements, integrating the team with the appropriate procurement mechanism, and front-loading key decision-making to driving discipline in avoiding unnecessary client change.

I fully endorse the viewpoint taken in this report that DfMA is not just a technical solution. It is a philosophy, and that philosophy needs to be embedded early in the project and, wherever possible, translated into a programme-wide approach.

The benefits case for DfMA is as applicable to traditionally built projects as to those that are aiming for higher levels of pre-manufactured value (PMV). That benefits case is underpinned by doing more design and planning work early to de-risk outcomes and leveraging the ability to use more standardised solutions and supply chain engagement. This Overlay clearly sets out the core tasks that need to be executed in order to make that an effective strategy.

The other point that is well made in this new Overlay is the role of digital in enabling a DfMA approach. The ability to create a digital thread through design to manufacture to assembly and construction, and then into operations, has long been talked about. In a world where insurers and funders will increasingly want better digital verification of the assets we produce, the power of digital manufacturing will increasingly be shown in positive contrast against the lack of clarity inherent in analogue, site labour-intensive traditional delivery. The concept of a 'digital twin' will only really be achieved in practice through digital manufacturing and the application of advanced product quality planning principles, and then assembly and integration with traditional works digitally verified on site. This is a future challenge as much to the MMC industry as it is to the traditional build sector. There will be an increasing need to use technology to be scalable and assured as opposed to just transferring on-site process failures into factories.

As we continue to see Government policy directly and indirectly promote MMC adoption and more and more clients explore its adoption on projects and programmes, we all need to embrace the thinking set out in this new Overlay. It should become a key project management tool for those wanting to ensure they reflect best practice. We need to use this framework to quickly move from the all too common practice of shoehorning MMC as an afterthought into a bespoke designed scheme after a planning consent has been obtained, to an approach where the design is optimised early for higher PMV either through a specific system or a generic application of principles that leave options open for further market engagement. When this is done well, clients will reap the benefits of earlier cost and schedule certainty that are so often crucial to their schemes' viability. We should also use this approach to address the industry's carbon, productivity, safety and quality challenges, which are all bearing down on it with increasing pressure.

I commend this DfMA Overlay to the industry and would like to congratulate the RIBA and the Steering Group and authoring team that have committed the time to make this come to life. I look forward to using it in my own business as a guide to helping commissioning clients think differently about how they set up their investments or policies for success and also to help the manufacturing supply chain optimise its proposition to end clients.

Mark Farmer
founder and CEO of Cast Consultancy and
UK Government MMC Champion for Homebuilding

CASE STUDY

Interdisciplinary Biomedical Research Building, University of Warwick

© Jack Hobhouse

Date completed: 2021	**Sector:** Education	**Value:** £30m

Client: University of Warwick Estates Department

Architect: Hawkins\Brown

Contractor: Willmott Dixon

Manufacturer(s):

Techcrete	(precast concrete panels/ PCE precast concrete frame structure)
Wiehag	(CLT and Glulam timber structure)
Structal UK	(unitized anodized aluminium curtain wall)

MMC categories used:

- Category 3: pre-cast concrete frame (columns, walls, floors, staircases), Glulam frame (columns, beams) CLT floors and roofs, CLT staircases.
- Category 5: unitised curtain-walling system, pre-cast concrete cladding with integrated window assemblies, M&E pre-packaged plant and distribution.

A five-storey building supporting interdisciplinary research at the School of Life Sciences and Warwick Medical School at the University of Warwick. As well as a 400-seat lecture theatre, it has a central 'lab village' core surrounded by open-plan write-up areas, office space and collaboration zones.

Benefits of the DfMA approach

A DfMA approach led to a design that included self-finished pre-cast concrete and CLT/glulam structural elements manufactured off site, assuring the client of high-quality finishes throughout. Fewer workers were needed on site, allowing distancing throughout the pandemic and minimizing programme delays.

© Jack Hobhouse

> This fantastic building has been delivered during exceptional times and is a testament to the tenacity and commitment shown by all those involved in designing and building it from the construction industry. Thestrategy taken in using modern methods of construction and a strong focus on sustainability and safety has paid off.'
>
> **James Breckon**, Director of Estates, University of Warwick

About the report

The first edition of the DfMA Overlay to the RIBA Plan of Work was published in 2016. It was quickly embedded across the industry as a welcome project management guide for all members of the project team implementing modern methods of construction (MMC).

Over the five years since, not only has the RIBA Plan of Work been updated, but the drivers behind, thinking about, and experience in DfMA, which stands for 'design for manufacture and assembly', have developed significantly.

This new edition accounts for that evolution with an updated Overlay aligned to the 2020 RIBA Plan of Work (see page 63), supported by an overview of the industry's rapidly maturing market readiness.

It is for everyone involved in commissioning, funding, insuring, managing, designing, manufacturing, supplying and building construction projects at every scale in all sectors, including:

- agents
- architects
- building control officers
- construction insurers and warranty providers
- construction project managers
- construction supply chain partners, including product manufacturers
- engineers
- financiers, funders and investors
- main contractors
- planners
- public and private clients
- quantity surveyors and cost consultants
- specialist consultants
- sub-contractors, including installers.

Objectives

DfMA must be established as the default approach so that the systems and processes that underpin it are better understood by clients and become second nature to everyone else involved in the design, manufacture and assembly of buildings.

There are four reasons why this is important.

1. It will smooth the way to achieving the transformation that the UK Government has outlined for the procurement of its construction pipeline (up to £37 billion in 2021) in many policy initiatives, culminating most recently in the *Construction Playbook* and the Value Toolkit. By involving project team members earlier and requiring a higher degree of design resolution before going on site, DfMA avoids waste and inefficiency, leading to better cost and time certainty as well as cost savings.
2. It will strengthen efforts to address the safety of buildings following Dame Judith Hackitt's review of building regulations and fire safety and supports the Building Safety Bill. By actively looking to do more construction in safer, more closely controlled and factory-like conditions, DfMA generally improves both safety during construction and the quality of the end-product.
3. It will help the construction industry to overcome many of its other long-standing and well-documented shortcomings, notably in productivity, labour supply, process and material efficiency, in-use performance, information management and risk management. Done optimally, DfMA with MMC – especially digitally-enabled offsite processes – addresses all of these concerns.
4. It will help the construction industry to prepare for the inevitable challenges predicted by current global trends, including potentially catastrophic changes in our climate, air quality, biodiversity, natural habitats, availability of natural resources and materials, population size, urbanisation, housing provision and infrastructure capacity.

Pace of adoption

While DfMA does not alter the fundamentals of good design and production, which have always been about getting the best possible outcomes for clients and communities, it does enhance traditional ways of working, especially if it leads to MMC.

This can come as a culture shock and trip up the unwary and so we acknowledge two things.

First, DfMA in construction is still maturing and cannot deliver the desired transformation overnight. Even with the level of pump-priming of the market for MMC intended by the UK Government (see *Chapter 2, Drivers of change*), the hoped-for improvements from DfMA are likely to be only gradual, with plenty of fuel for die-hard sceptics along the way as project teams find their feet. However, since it is our current best bet for meeting the global challenges ahead, we owe it to society to make it work.

Second, we accept that there will always be a place for what is sometimes called the 'traditional' or 'business-as-usual' approach to design and construction, especially in smaller projects where highly crafted, bespoke solutions are the order of the day. Indeed, since every project is to a certain degree unique, there will always be a need for these traditional approaches, even on the most innovative schemes. Even so, integrating a DfMA approach will ensure that opportunities to adopt MMC are not missed.

DfMA as a philosophy

The consultees to the Overlay were keen to highlight that, as much as DfMA is a technical process, it is also a philosophy that should be seen as an extension or evolution of the designer's ordinary way of working.

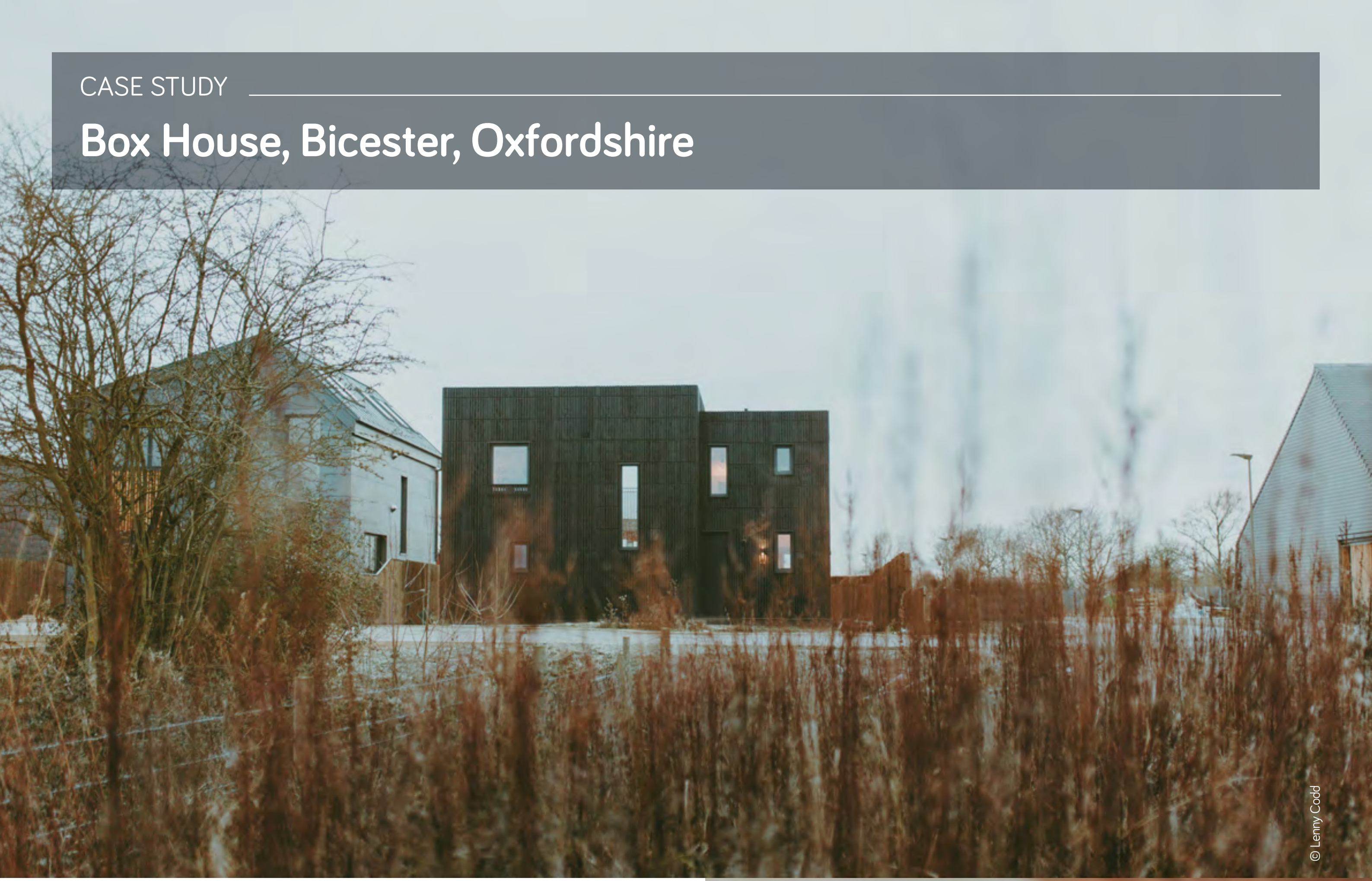
After all, designers have always tried to do the best for their clients, their buildings' users and society as a whole. This process merely helps them to go further.

In particular, the consultees wish to dispel the myth that DfMA is a barrier to great architecture or reserved just for a few new-build sectoral building types.

As the case studies in this report show, the judicious, mature expression of DfMA can produce extraordinary, award-winning architecture, with few limits on where it can be applied. It is relevant to all kinds of project, including smaller ones and work on existing buildings, and should be used by all kinds of organisations, including micro-businesses.

CASE STUDY

Box House, Bicester, Oxfordshire



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Date completed: Autumn 2017	**Sector:** Residential	**Value:** £201,000

Client: Private

Architect: Studio Bark

Contractor: Studio Bark Projects

Manufacturer: U-Build + Cut & Construct

MMC categories used:

- Category 2: pre-manufacturing — 2D primary structural systems.
- Category 6: traditional building product-led site labour reduction/ productivity improvements

Box House is a pioneering 'demonstrator home' at Graven Hill, Bicester that featured in Channel 4's *'Grand Designs: the Street'* mini-series. The architect developed a modular flat-pack timber construction system (called 'U-Build') that simplifies construction for the self-builder.

Benefits of the DfMA approach

U-Build uses a DfMA workflow, providing upfront certainty regarding quantities and costs.

The solution includes self-finished structural elements CNC-cut from standard sheet sizes, minimising waste.

The precision of the CNC cutting made assembly on site straightforward. Unskilled workers were able to complete a significant structural timber frame quickly using only basic hand tools and manual handling (i.e. there was no specialist heavy lifting gear involved).

U-Build is connected using bolts and is based upon a consistent grid module, employing circular thinking to enable disassembly and reuse.

> 'The architectural aesthetic of the system emphasises simplicity and unity, employing timber as both structure and internal finish. The result is an authentic celebration of material, manufacturing and construction processes.'
>
> **Nick Newman**, Studio Bark / U-Build

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Introduction

Introduction

What is design for manufacture and assembly?

Historical roots

Design for manufacture and assembly (DfMA) is a term originating from the world of manufacturing, where it emphasises two practical design considerations – how a component is manufactured, and how it will be assembled into a product – that together have the potential to improve the efficiency of production. Since these considerations are frequently overlooked in favour of design for use, especially in construction, the emphasis is useful and welcome.

The term originally applied to factory-made, mass-produced components that would be assembled into larger mass-produced products destined for an end-user, all in a factory.

With advances in manufacturing techniques, it now commonly applies to making products that can be tailored to varying degrees in a process known as mass customisation. As well as giving consumers more choice, being able to mass customise has widened the relevance of DfMA to include the design of more complex, larger ticket, smaller sales volume products, such as buildings.

Tailored products at low prices: mass customisation

Mass customisation is the process that allows manufacturers to customise their products by varying their production processes without affecting their ability to charge low (i.e. mass-production) prices.

Enabled by digital technology, it is made possible with automation and innovative manufacturing techniques that help manufacturers to produce interchangeable components, perhaps in different sizes and finishes, which can be combined in numerous ways to satisfy customers' specific needs. It is also made possible by reducing the time and cost of changing manufacturing process set-ups for different variants of a product or component.

Because different components (albeit with a family resemblance) are made on just one production line or by the same supply chain rather than several different ones, and made to standardised parameters, the process remains as efficient, or nearly as efficient, as the mass production approach.

In manufacturing, the DfMA process is specifically aimed at improving production efficiency, optimally balancing, on the one hand, market demand for affordable product quality, reliability, aesthetic appeal and all the characteristics that drive sales with, on the other hand, low manufacturing costs, safety, speed, production control, regulatory compliance and other advantages that drive efficient production.

Its development was motivated by commercial considerations, i.e. profit and a need to be able to supply a wider range of products cost-effectively. More recently, the scope has widened to allow social and environmental motivations in response to scientific evidence, market demand, policy incentives and tightening regulations.

DfMA in construction

Applied to the construction sector, DfMA is about finding ways to rationalise the design process, improve the selection of materials, and optimise the planning and logistics of building. In particular, it exploits opportunities to design built assets using a limited variety of repeated, preferably standardised, components, sub-assemblies or assemblies that can beneficially be manufactured off site, transported to site viably, and assembled there safely, quickly and straightforwardly.

These components or assemblies can be for just a single project or, usually with mass customisation, many different projects.

What are the benefits?

The reasons why we should want to design for offsite manufacture are very similar to the reasons why car manufacturers prefer to design their cars for production in a factory rather than assembling them on buyers' drives.

Design for manufacture makes components simpler to make; design for assembly makes products easier to assemble. The DfMA process combines the functionality of numerous parts into fewer components to achieve the same or improved functionality.

Factory benefits

According to a 2016 Buildoffsite report, on-site conditions can be 80% less safe than factory conditions. Construction in a shed does not achieve a safer environment on its own, but manufacturing practices can – especially with more use of industry standards and ensuring that there is competition in pricing.

On-site labour is more than twice as expensive as factory-based labour, productivity in a factory reaches 80% compared to just 40% on site, and waste is almost entirely eliminated in a factory setting. On top of that, production is more easily controlled and inspected in a factory. Overall, therefore, build quality is improved, outcomes are more certain and costs are minimised.

On-site benefits

Of course, very few buildings can be *completed* in a factory the way a car can, and so they are always partly made on site. However, because the on-site assembly has been planned, optimised and simplified, less on-site labour is needed and there are fewer preliminary costs and overheads.

Compared to business-as-usual construction, work designed with a DfMA mindset should:

- happen more quickly
- need:
  - less material
  - less labour
  - less associated management and paperwork
  - less rework
- result in:
  - less waste
  - fewer defects
  - safer work sites.

As well as reducing risks, the aggregate cost savings associated with these benefits can be significant. Note, however, that to achieve these benefits, the interfaces between on-site and offsite elements have to be managed effectively.

Environmental sustainability benefits

The process also leads to solutions that, regardless of the predominant material used, can be inherently more environmentally sustainable than traditional construction in a variety of ways:

- **Less waste:** Manufacture in a factory setting means better planning, better production control, fewer errors and, therefore, more efficient use of material and less material waste.
- **Lower transportation costs, better air quality, less noise pollution:** Since only what is needed for the building is transported to site, offsite manufacture minimises embodied transport carbon costs both in getting components, sub-assemblies and pre-assemblies to site and in removing waste from the site. It also limits negative impacts on air quality and noise pollution for the same reasons.
- **Less on-site energy and water use:** The speed and ease of assembly minimises on-site energy and water consumption, with resulting environmental benefits.
- **Less material:** Better, earlier design resolution leads to less material redundancy in, for example, unnecessarily large ceiling voids. Repeatedly applied across whole programmes of work, this has the potential to significantly reduce material use.
- **Better energy performance in use:** The accuracy and quality of components, sub-assemblies and pre-assemblies and their ease of assembly on site minimises the risk of poor workmanship, helping to close the performance gap between design intent and asset in use. For example, the use of offsite cut cross-laminated timber (CLT) can lead to outstanding airtightness, which reduces operational energy loads, with huge carbon savings over the asset's whole life.
- **Encourages circular economy:** Some components, sub-assemblies and pre-assemblies can be more easily reused, helping with both the project's whole-life carbon cost prognosis and efforts to activate the circular economy.

Optimising the benefits

To reap the full benefits, components, sub-assemblies and pre-assemblies designed off site should be standardised to the greatest possible extent, preferably in a way that complies with nationally or internationally agreed universal standards *(see Chapter 6, What will the near future look like?)*.

Standardised components, sub-assemblies and pre-assemblies are preferred on the assumption that they are tried, tested and therefore known to work, and because they avoid 'reinventing the wheel', saving time and design fees, and reducing rework and risk.

Standardisation also enables market competition (see *Standardisation?* on page 13), which is a critical requirement in most procurement processes.

Measuring the benefits

A proxy measure of the success of DfMA is the project's pre-manufactured value (see *What is pre-manufactured value?* on page 13), which expresses the amount of money spent off site as a percentage of the total project budget. Although not true in all cases, a higher percentage can lead to a more efficient – and therefore better value – project.

Used judiciously in combination with other tools (for example, the Value Toolkit – see *Value Toolkit* on page 23), the measure is a useful way of framing project ambitions and monitoring progress.

The Construction Industry Research and Information Association (CIRIA) recently published a research-based methodology for quantifying the benefits of offsite construction in educational buildings. It can be used by clients and construction management teams to 'assess the value and benefits achieved on projects'.

What is pre-manufactured value?

Pre-manufactured value (PMV) is a measure of the proportion of construction that happens off site. It is thus an indicator of project efficiency.

Expressed as a percentage, it is (according the Construction Leadership Council's (CLC) *Housing Industry Metrics*) calculated as the project's gross capital cost less the cost of prelims (site overheads) and site labour, divided by the gross capital cost.

The higher the PMV, the smaller the proportion of the capital cost that was spent on prelims and on-site labour and so, in theory, the greater the project's efficiency. The CLC sets the benchmark at 40%: anything above that is better than business as usual.

It is also worth noting that, since very few buildings are constructed entirely on site or off site, the PMV will never be 0% or 100%.

Standardisation

A large part of the value that comes from DfMA (and MMC more generally) derives from efficiency gains from making the same or similar components and assemblies repeatedly, especially if a standardised process is used to achieve economies of scale.

Standardisation constrains solutions to those that are known to work, in a sense trading the flexibility to tailor for quality assurance. By avoiding 'reinventing the wheel', it has the potential to speed up the design and assembly phases of projects.

The standardisation of interfaces is particularly helpful in that it facilitates mass customisation and interoperability, opening markets up to more players, thus enabling market competition.

Note that standardised components and assemblies do not stand still. Instead, they evolve in the light of feedback from users, leading to ever-better solutions.

Many other aspects of DfMA benefit from standardisation, including design processes, information exchanges (especially digital ones) and management systems, helping all the many different parties to 'sing from the same hymn sheet' and thus avoid wasted effort or rework.

The ultimate expression of standardisation is when it is written down as a nationally or internationally agreed standard, such as those produced by the BSI or ISO.

CASE STUDY

The Forge, 105 Sumner Street, London SE1

Date completed: July 2021 **Sector:** Commercial offices **Value:** £80m

Client: Landsec

Architect: Bryden Wood

Contractor: Sir Robert McAlpine, Mace

Manufacturer(s):
Easi Space, DAM Structures, NG Bailey, Hall & Kay, Armstrong, Hotchkiss

MMC categories used:

Category 5:

- floor cassettes: fan coil modules; pipework modules; ComFlor distribution/lighting modules.
- vertical risers: pipework; electrical; sprinklers; ductwork.
- infrastructure: roof plant room multi-service distribution modules; heat interface unit assemblies; packaged pump rooms; packaged LV switchrooms; plant equipment skids.

Category 7:

- pre-manufactured ComFlor beams;
- pre-manufactured walkway system;
- platform temporary works system;
- steelwork prefabricated as components;
- handrail system;
- use of:
  - remote monitoring of concrete slab temperature to allow accurate reading of concrete strength maturity;
  - automation for lifting and placement of all structural components.

When built, the Forge will be the world's first major commercial development to use a platform approach to DfMA and the UK's first to be net-zero carbon in construction and operation.

Benefits of the DfMA approach

With a platform approach to DfMA and BIM technology, the partners optimised a structural frame that could be precisely manufactured offsite and assembled onsite using an automated assembly process.

They predict a 22% reduction in embodied carbon and a 13.5% productivity gain from automated construction processes and using a multi-skilled workforce. The scheme will also eliminate all work at height.

> The Forge is a landmark moment in construction. An innovative design company, a bold client and forward-thinking manufacturer coming together to show the world how we can build the future.'
>
> **Jaimie Johnston**, Bryden Wood

What is offsite construction?

Offsite construction (also known as 'offsite manufacturing', 'offsite production' or 'prefabrication') is the collective term for all the construction of a built asset that happens away from the work site and that adds value compared to business as usual.

Offsite construction includes work that happens in what are sometimes called 'near-site', 'field' or 'flying' factories, which are generally temporary or mobile fabrication facilities near or adjacent to the main work site.

What materials are involved?

The DfMA process does not favour one structural material over any other. As with any project, the structure and the materials it is made from are chosen after due consideration of what offers the best solution for its unique set of circumstances. (See *Chapter 4, Choosing the best options* for more on this.)

The only time that this might not be true is when the choice of material is constrained by the project brief, either overtly or because achieving a specific goal is only possible using a certain class of material.

The categories of the MMC framework identify seven 'genres' of output, differentiated by their predominant material:

1. mass-engineered timber
2. timber-framed
3. timber-framed/concrete combination
4. concrete and cement-derived
5. light-gauge steel-framed
6. hot-rolled fabricated steel
7. hot-rolled/light-gauge steel combination.

Of course, these are just the materials that components and assemblies are made from and say nothing about the foundations and other structures that they will be anchored to on site, or new materials. Generally speaking, buildings described as having been built using MMC will, in fact, nearly always include at least some element of business-as-usual construction as well.

What are modern methods of construction?

DfMA will often (but not always) lead to modern methods of construction (MMC), a broad catch-all term for processes and building methods that are designed to improve productivity or reduce the need for labour, or both, and lead to better long-term outcomes.

The word 'modern' in this context is rather misleading. The methods and their underlying rationales and principles have been around for decades. However, they are described as 'modern' because they have yet to be adopted into the mainstream. This is changing in the light of opportunities arising from a confluence of innovations in the fields of digital technology, automation, additive manufacturing and robotics, which certainly *are* modern.

The most important of these modern methods, and the one that the UK Government is increasingly invested in, is the platform approach to design and construction (see *Chapter 6, What will the near future look like?*). Unified under common standards, platform-based DfMA, or P-DfMA, will enable outcomes focused on best value and entail any number of delivery methods, including those that fit into the Categories of MMC (see *Categories of MMC* on page 16).

Categories of MMC

The UK Government's Ministry of Housing, Communities and Local Government's Joint Industry Working Group on MMC identified seven categories of MMC for the mortgage finance, insurance and valuation communities. Although specific to residential development, these numbered categories, detailed below, are proving useful for improving communication and understanding in other sectors too.

Category 1: Pre-manufacturing (3D primary structural systems)

This category includes systemised approaches based on volumetric construction involving the production of 3D units in controlled factory conditions prior to final installation. Volumetric units can be brought to final site in a variety of forms, ranging from the basic structure only to one with all internal and external finishes and services already installed.

The system includes structural performance. Full volumetric units in apartment buildings can include both apartment spaces and common area spaces. Mini-volumetric structural units can include bathroom pods and similar components that are structurally stacked and loaded.

Category 1 systems can be either point-loaded or line-loaded and the decision will be governed by matters such as the internal spans and the flexibility required for internal layouts.

Line-loaded systems limit the room width to the maximum width that can be transported. Structural openings are generally up to 1.8m wide, although the introduction of hot rolled steel or lattice beams will increase the opening size. This technology is more light weight, minimising the cost and depth of foundations. It is suitable for buildings up to 10 stories, but can be higher with a reinforced concrete frame core to tie the modules into.

A point-loaded system is usually more costly but has the advantage of being able to provide a more open-plan layout. The floor build-up is generally deeper than with a line loaded system but the boxes are more stable, with tighter tolerances, making a point-loaded system more suitable for higher rise buildings.

The variants include:

a. structural chassis only – not fitted out
b. structural chassis with internal fit-out
c. structural chassis, fitted out and including external cladding/complete roofing
d. structural chassis and internal fit-out, including 'podded' room assemblies, such as bathrooms and kitchens etc.

The variants can be used in the following three configurations:

1. whole building systemised
2. hybrid construction – part-systemised, part-traditional (e.g. traditional core/ground-floor podium)
3. hybrid construction – secondary structure to enhance system performance (i.e. build at height).

Category 2: Pre-manufacturing (2D primary structural systems)

A systematised approach using flat panel units for basic floor, wall and roof structures of varying materials, which are produced in a factory environment and assembled at the final workface to produce a completed 3D structure. The most common approach is to use open panels, or frames, which consist of a skeletal structure only, with services, insulation, external cladding and internal finishing being installed on site.

More complex panels – typically referred to as closed panels – involve more factory-based fabrication and include lining materials and insulation. These may also include services, windows, doors, internal wall finishes and external claddings. The system includes structural performance for primary walls and all floors. (Note that this excludes the unitised or composite external walling systems that are not load-bearing: these are included in Category 5.)

The variants include:

a. basic framing only, including walls, floors, stairs and roof
b. enhanced consolidation – insulation, internal linings etc.
c. further enhanced consolidation – insulation, linings, external cladding, roofing, doors, windows.

Category 3: Pre-manufacturing components (non-systemised primary structures)

This category includes processes that use pre-manufactured structural members made of framed or mass-engineered timber, cold- or hot-rolled steel or pre-cast concrete. Qualifying members include load-bearing beams, columns, walls, core structures and slabs that are not substantially in-situ workface-constructed and are not part of a systemised design.

This category, although focused on superstructure elements, also includes sub-structure elements, such as prefabricated ring beams, pile caps, driven piles and screw piles.

The variants include:

a. driven/screw piling
b. prefabricated pile caps/ring beams
c. columns/shear walls/beams
d. floor slabs
e. integrated columns, beams and floor slabs
f. staircases
g. pre-assembled roof structure – trusses/spandrels.

Category 4: Additive manufacturing (structural and non-structural)

This category comprises remote, site-based or final workface-based processes that print parts of buildings in various materials, based on digital design and manufacturing techniques.

The outputs include:

a. substantive structural forms/components
b. non-structural components.

Category 5: Pre-manufacturing (non-structural assemblies and sub-assemblies)

This category comprises a series of different pre-manufacturing approaches, including unitised non-structural walling systems, roofing finish cassettes or assemblies (where not part of a wider structural building system), non-loadbearing mini-volumetric units (sometimes referred to as pods) used for highly serviced and more repeatable areas, such as kitchens and bathrooms, utility cupboards, risers, and plant rooms. Pre-formed wiring looms and mechanical engineering composites also fall into this category.

Conventional masonry, site-constructed schemes using conventional building products such as windows and door-sets – which might otherwise be part of the fabrication process in other pre-manufacturing categories – are not included as sub-assemblies or components in this category unless there is a further level of consolidation from traditional configurations.

This category also excludes any structural base elements that composite assemblies are fixed to and which are included in Categories 1 to 4. Any structure in this category is purely to support the sub-assembly in transit or during the installation phase.

The variants come in two categories:

Volumetric podded assemblies:

a. whole bathroom assemblies (including enclosing structures)
b. kitchen assemblies (including enclosing/supporting structures)
c. assemblies that combine bathrooms and kitchens (including enclosing/supporting structures)
d. in-unit M&E central equipment assemblies (such as utility cupboards etc.)

Panelised/linear assemblies:

e. non-structural façade assemblies (including glazing, solid cladding, metalwork)
f. roof assemblies/cassettes – pre-finished roof sections (including structure to support own weight)
g. in-unit M&E distribution assemblies
h. infrastructure M&E assemblies – vertical risers/main distribution
i. infrastructure M&E assemblies – central plant and equipment
j. floor cassettes with horizontal services/finishes added
k. partition cassettes with horizontal and vertical services/finishes added
l. door-sets (pre-hung, finished with ironmongery).

Category 6: Traditional building product-led approaches that reduce site labour and/or improve productivity

This category includes approaches that adopt traditional single-building products manufactured in large format, pre-cut configurations or with easy jointing features to reduce the extent of the site labour required to install them.

The variants include:

a. large-format walling products for external walls
b. large-format walling products for internal walls
c. large-format roofing finishes
d. pre-sized and cut-to-measure traditional components – component-level systemisation
e. easy site installation/jointing/interfacing features – brick slips, modular wiring, flexible pipework.

Category 7: Site process-led site labour reduction/productivity/assurance improvements

This category encompasses approaches falling outside Categories 1 to 6 that use innovative site-based construction techniques and harness site process improvements. It also includes factory-standard workface-encapsulation measures, lean construction techniques, physical and digital worker augmentation (including exoskeletons and other wearables), workface robotics, drones, verification tools and adoption of new technologically advanced plant and machinery.

The variants include:

a. site encapsulation measures – weatherproof and environmentally controlled enclosures
b. use of standardised or sacrificial temporary works – modular scaffold, tunnel-form in-situ concrete, insulated concrete formwork
c. use of BIM-connected lean delivery frameworks – digitally enabled workflow planning
d. site worker visual augmentation (i.e. augmented reality (AR) or virtual reality (VR) technology)
e. site worker physical augmentation (i.e. exoskeletons, assisted materials distribution etc.)
f. site worker productivity planning tools (GPS, wearables etc.)
g. site process robotics and drones (rebar, masonry, plastering, decorating, surveying etc.)
h. autonomous plant and equipment and drones (driverless cranes, diggers etc.)
i. digital site verification tools (photogrammetry, site worker video, LIDAR scanning etc.).

CASE STUDY

Swing Bridge, Crystal Palace Park, London

Date completed: January 2021	**Sector:** Infrastructure	**Value:** £85,000
Client: Friends of Crystal Place Dinosaurs		
Architect: Tonkin Liu		
Engineer: Arup		
Contractor: Cake Industries		
Manufacturer: Cake Industries		
MMC categories used: Category 3		

The small bespoke swing bridge allows pedestrian access to the Crystal Palace Dinosaur islands. It demonstrates how a DfMA mind-set can influence even the smallest, most bespoke projects.

Benefits of the DfMA approach

The architect proposed that the whole bridge be manufactured off site using an innovative laser-cut skeletal comb structural technique.

Made from 10 mm-thick steel plate by locally based fabricators, the project minimiswes material waste and reduces the amount of welding by 50%.

The length of the bridge was constrained by the maximum size of the galvanizing tank, requiring the design to be refined.

> The bridge has not only solved a practical challenge, but has added to the beauty of the park, brought together the community and raised our capabilities as a charity. Visitors love the bridge, giving overwhelmingly positive, deep appreciation.'
>
> **Ellinor Michel**, Friends of Crystal Palace Dinosaurs

2

Drivers of change

Drivers of change

Why the shift from business as usual?

Poor productivity

The need for DfMA as a critical process in delivering MMC is evident in the bigger picture. The global construction industry's record on productivity improvements in comparison to the economy as a whole is poor and has been for decades. Closing this gap would be worth $1.6 trillion each year, an enormous sum of money that is fuelling a gold rush by private R&D investment (see below).

Growing global demand

At the same time, the sector is facing unparalleled challenges on several fronts. Foremost among these is the prediction for substantial human population growth, with the consequential need to build more housing and supporting infrastructure. The scale of the challenge is considerable: RICS with Autodesk calculated that the global industry will have to complete 13,000 new buildings **a day** for the next 30 years to keep up with demand.

Labour shortage

The industry also faces a severe labour shortage, with an ageing workforce and contractors unable to attract young people to jobs that are poorly paid, physically exhausting, comparatively dangerous and exposed to the elements. As the Farmer Review, *Modernise or Die*, pointed out in 2016, this was already leading to cost inflation in a way that caused projects to stall in the UK and would, it predicted, leave the country short of up to 25% of the workforce needed to meet demand by 2026. The effect of Brexit is likely to exacerbate this.

Policy action

Mark Farmer's influential report also confirmed the long-suspected diagnosis of other deep structural problems in the sector, including low productivity, poor predictability, fragmentation, skills shortages, and a lack of research, development and investment in innovation. Its recommendations were mostly accepted by the UK Government and paved the way for the Construction Sector Deal in 2018.

The Construction Sector Deal

The Construction Sector Deal is essentially a statement of intent by the UK Government to guide future policy. The idea was to substantially boost the construction sector's productivity and reduce its environmental impact, improve the efficiency and reduce the whole-life cost of new projects, helping the UK to get good long-term value for its publicly funded projects. As the largest client in the country, the Government's example could sway practice more widely, which would be good for UK PLC.

The Deal set the following aspirational targets for publicly funded capital projects:

- deliver 50% faster
- reduce whole-life costs by a third
- reduce lifetime carbon emissions by half
- raise productivity by 15%.

Presumption in favour of offsite construction

The Government kick-started the improvement in two ways. First, in its Autumn 2017 budget, the UK Treasury announced that it would take 'a series of steps to improve the cost effectiveness, productivity and timeliness of infrastructure delivery'. Included in this was a 'presumption in favour of offsite construction' where it represented 'best value for money' for publicly funded capital build projects from 2019, starting with projects initiated by the Departments for Transport, Health, and Education, and the Ministries of Justice and Defence.

Industry transformation

Second, the Government launched a formal Transforming Construction Challenge, co-investing £170 million of public money to encourage the development and uptake of MMC in the construction sector, specifically to:

- adopt an offsite manufacturing approach
- embrace digital technologies to improve assurance, efficiency and performance feedback to design
- shift to valuing whole-life outcomes rather than outputs.

Part of the money established the Construction Innovation Hub (CIH), which is today driving fresh thinking, stimulating R&D innovation and influencing public policy. It produced the Value Toolkit, which is helping to drive the adoption of DfMA as the default setting in the industry.

Value Toolkit

The product of the CIH's Procure for Value workstream, the Value Toolkit aims to support public sector clients in switching away from lowest cost to greatest long-term value based on the Capitals Model.

According to the CIH's website, the Value Toolkit's primary purpose is 'to support better decision-making throughout the whole investment life cycle from business case through to procurement and delivery and operation, improving overall sector performance consistent with key policy objectives, such as driving MMC, delivering social impact and accelerating the path towards Net Zero'.

Its success will rely in part on the development of a platform construction system, which is being pursued by the CIH's Platform Design Programme (see *Chapter 6, What will the near future look like?*).

Construction Playbook

The *Construction Playbook: Government guidance on sourcing and contracting public works projects and programmes* was published at the end of 2020 by the Cabinet Office and co-developed by the Construction Leadership Council in consultation with industry.

While not mandatory, public clients must either adopt its guidance or have a good reason why they shouldn't.

Among many other improvements, it aims to 'drive innovation and Modern Methods of Construction' and 'standardise designs, components and interfaces'. Its strategic approach includes having a 'product mindset', which means 'learning the lessons of repeatability from manufacturing, often with extensive use of digital design and Design for Manufacture and Assembly'.

There is evidence that the change envisaged in the Playbook has begun. For example, in April 2021, Homes England, the Government's housing agency, announced that it was seeking strategic partners to enter into a multi-year grant agreement to deliver affordable housing. To succeed, they should, among other things, adopt MMC with a minimum 55% PMV.

Hackitt review

Finally, the lessons emerging from the Hackitt review following the Grenfell Tower fire have put build quality, testing and competence under the spotlight as never before. There is now a consensus across the industry about the need for a 'golden thread' of joined-up information that makes project initiators accountable to building operators and users, which will be enforced through a new Building Safety Act.

This has self-evident implications for DfMA – not just for DfMA's potential to bake in health and safety quality but also for the importance of standardising project information in a way that can be reliably passed on in a 'golden thread' chain of custody beyond the end of Stage 5, Manufacturing and Construction.

The UK Government is not alone in betting on DfMA and MMC. Many other governments are equally invested, notably Singapore, Japan and the Nordic countries. China is driving the revision to the ISO standards for modular construction.

Industry action

The drive isn't coming just from governments. Private R&D backing for what is known as ConTech, PropTech and InfraTech has ramped up considerably over the past decade too.

Whereas governments are targeting societal challenges and securing taxpayer value, private investors have their eye on the commercial opportunity. In the USA, the sector is attracting billions of dollars as the digital expertise of Silicon Valley eyes the main chance to yank construction, currently languishing just above agriculture as the least productive industry in the world, up to the performance of the manufacturing sector.

Notable recent global deals include Japanese firm Sekisui's hook-up with Urban Splash, Goldman Sach's investment in TopHat, and Softbank's gargantuan (but ill-fated) $865 million investment in Katerra. With the global construction industry forecast to be worth in excess of $24 trillion in 2021, and productivity gains of 40% possible from digital tech, that fever is only going to increase.

The UK construction industry is also responding. Many of the major players are investing to different degrees, some to vertically integrate manufacturing capability, others to horizontally integrate MMC skills. The industry has clubbed together in various ways, too, setting up the Infrastructure Industry Innovation Partnership (i3P) to stimulate fresh ideas and sponsor innovation, and funding the Supply Chain Sustainability School to train up the future workforce.

Overall, it looks like the global construction sector has acknowledged the challenges ahead and agreed that construction industrialisation through DfMA and MMC is the best way to meet them.

CASE STUDY

'Q2', King's Cross Sports Hall, King's Cross, London

Date completed: 2020	**Sector:** Civic	**Value:** £8m

Client: Argent and London Borough of Camden

Architect: Bennetts Associates (Concept) and Stride Treglown (Executive)

Contractor: BAM Construction

Manufacturer: Binderholz

MMC categories used:

- Category 2: CLT wall and roof panels
- Category 3: glulam beams and staircases

Q2 is a 2,017 m² sports hall for public use comprising four standard badminton courts, a basketball court, a volleyball court and a five-a-side football pitch, with a smaller fitness suite on the first floor.

Benefits of the DfMA approach

Its position above railway tunnels necessitated a lightweight solution, informing the decision to use CLT. The architect visited exemplar CLT buildings to ensure that the design constraints and visual implications were identified before technical design progressed.

Their DfMA approach used federated BIM models to coordinate the design with the CLT manufacturer and M&E subcontractors, ensuring the accurate sizing and placement of openings.

Because the architect was operating in a sophisticated BIM environment, the client was able to review the rendered BIM model interactively at the conclusion of Stage 4 to verify the detailed design decisions.

> The well-presented lightweight CLT frame of Q2 represents an elegant solution to problems caused by the three railway tunnels running just 3 m below the site.'
>
> **Chris Charlton**, Stride Treglown

3
Market readiness

Market readiness

If the benefits of DfMA and MMC are so significant for clients and society, and there is so much private R&D from industry and pump-priming of the market by Government, why are they not yet in the mainstream?

The simple answer to this good question is because there are road bumps. Some are genuine constraints imposed by construction's unique structural characteristics; others are about perception or habit; and still others endure simply because the appropriate technology is not yet widely adopted. However, the growing consensus is that there already exist good, scalable solutions for overcoming almost all of them.

Indeed, the main objective of the Government's *Construction Playbook* is to remove these market barriers in the context of public procurement (see *Public procurement and MMC* on page 31), which it hopes will provide the catalyst needed to change the industry more widely (see *The Construction Playbook's policies* below).

The Construction Playbook's policies

The *Construction Playbook* wants to leverage the Government's influence as the biggest client in the country to engineer the right conditions for improvements in the sector in order to achieve three cross-cutting priorities: health, safety and well-being; building safety; and 'build back greener'. In particular, it has 14 'policies' that are mandated on a 'comply or explain' basis. Under four categories, the policies will address the following issues.

Preparation and planning:

1. Publish commercial pipelines, which it hopes will give manufacturing investors the confidence to increase capacity (e.g. build factories).
2. Insist that projects assess the supply market's health and capability to take advantage of MMC. This will level the playing field so that MMC gets a fair look-in alongside business-as-usual procurement.
3. Develop portfolios and longer term contracting for appropriately innovative commercial partners. Again, this gives investors confidence that there will be a long-lived market for their outputs.
4. Harmonise, digitise and rationalise demand to accelerate the use of platform approaches. This will overcome the barrier to adoption imposed by intellectual property as well as yielding taxpayer value.
5. Embed digital technologies using the UK BIM Framework to standardise information management, which will help with the creation of a National Digital Twin (see *Chapter 6, What will the near future look like?*). Three major objectives here are to improve collaboration, facilitate the golden thread of information, and provide the feedback needed for a continuous improvement process (CIP) in quality assurance.
6. Insist on involving the supply chain early enough to influence the business case. This will enable the early collaboration and design freeze needed for the best results.
7. Focus on long-term social and environmental (as well as financial) outcomes rather than scope in specifications, using a Project Scorecard (currently under development).
8. Use benchmarks and 'should-costing' techniques to make whole-life value investment decisions that lead to better outcomes and better value for money.
9. Use evidence to determine the best delivery model for projects or programmes.
10. Ensure that contracts support collaboration and manage risk. Improving how risks are apportioned in contracts will incentivise the open, 'in it together' teamwork needed for successful offsite manufacture.

Publication:

11. Scrutinise proposals to ensure that risk is allocated appropriately.
12. Ensure payment mechanisms incentivise the desired behaviours and outcomes.

Selection:

13. Assess the economic and financial standing of suppliers before contracting with them to avoid the problems that arise when suppliers go out of business during the life of a contract.

Evaluation and award:

14. Ensure that suppliers of critical public works contracts have a contingency plan that protects the Government in the event that they become insolvent during the contract.

Readying the market in this way matters in the long run. This is because carrying on with business as usual looks like being insufficient for meeting the global social and environmental challenges ahead, which, left unmet, will have devastating consequences for the future of humanity and, therefore, the continued existence of markets.

If the case for enlightened self-interest weren't motivation enough, there are also significant commercial opportunities for those prepared to adopt new ways of working (see *Chapter 2, Drivers of change*). The global productivity gains alone equate to billions of pounds' worth of savings annually that would give those able to access them an extraordinary competitive advantage.

A healthy market is a competitive market and designers should apply DfMA in a way that permits healthy competition. Standards have a role to play here, as does the use of performance-based specifications.

While there are downsides involved in making the switch, the risks of not doing so are potentially even greater and will grow more so over time. The future is difficult to predict, but at some stage the adoption of new ways of working is likely to reach a tipping point. Those not on board will be left behind.

CASE STUDY

St Teresa's Sixth Form Centre, Effingham, Surrey

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Date completed: June 2018	**Sector:** Education	**Value:** £1.5m

Client: St Teresa's School

Architect: IF_DO

Contractor: Net Zero Buildings

Manufacturer: Net Zero Buildings

MMC categories used:

- Category 2: pre-manufactured lightweight steel and glulam frame
- Category 3: pre-manufactured SIPs, with external doors and windows pre-installed
- Category 5: pre-manufactured roof panels

The new 800 m² Sixth Form Centre for St Teresa's School comprises two separate blocks, one constructed using SIPs, the other using a lightweight steel and glulam frame, connected by a covered link.

Benefits of the DfMA approach

A DfMA approach produced considerable efficiencies, allowing the brief to be delivered to a tight budget. It also made for a quick build, important given the need to minimise disruption and the restricted site access.

Once the building was above the ground, it was completed in just three months, with just the external cladding and internal finishes completed on site.

> 'IF_DO's commitment, passion, expertise and drive has delivered an outstanding project on budget and on time. Their skill and dedication to detail has given St Teresa's the flagship Sixth Form Centre we had hoped for – more than could have been expected – that will enable the school to set itself on track to give young pupils studying for their A-levels the very best opportunity to achieve great things.'
>
> **Michael Bray**, Chair of Governors, St Teresa's School

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Mainstreaming MMC

So, what are the market road bumps and how are they being addressed?

Building supply and demand

There is a genuine chicken-and-egg conundrum holding back the mainstream adoption of MMC. On the one hand, demand is inhibited by the low supply capacity. On the other, suppliers are reluctant to increase capacity because of uncertain constancy of demand.

Breaking the deadlock has apparently been too big a risk for the industry on its own. Given the scale of foreseeable need and fast-approaching global challenges, and convinced of the case for DfMA and MMC, the UK Government has decided to intercede. Publishing its pipeline of future work, its presumption in favour of offsite construction, and the other policies in its *Construction Playbook*, will help to provide the necessary catalyst to reach a critical mass of capacity.

Large private clients are already doing something similar by applying DfMA and MMC approaches across their entire portfolios so that solutions are optimised over time and standardised to work across multiple similar buildings, reaping considerable economies of scale. In the DfMA Overlay, the planning and design work needed to take this portfolio-wide approach is considered a project in itself, covered by Stages 0–4.

Standards and interoperability have roles to play too. In particular, architects could start to think in terms of developing more configurable products that would enable manufacturers to address multiple markets, helping the shift to a more platform-based development (see *Chapter 6, What will the near future look like?*).

Reducing contractual risk

The disaggregated, fragmented nature of project teams discourages the collaborative behaviours that allow decisions to adopt offsite manufacturing and appoint project team members to be made early enough to optimise the DfMA process.

The propensity to delay early project team engagement is exacerbated by the UK's planning system, which incentivises putting off decisions that are critical for successful MMC before consent is secured and rushing to site as quickly as possible thereafter. The later the decisions and appointments are made, the more design rework is likely and the greater the opportunity costs, undoing many of MMC's advantages and unfairly blotting its copybook. In short, DfMA needs to be considered before the planning application is made. It generally becomes very hard to adapt designs once constraints related to planning permission are applied.

Although deeply entrenched and thus hard to shift, the problem could be overcome in some instances with the use of integrated project insurance and alliancing contracts (i.e. multi-party contracts where everyone is subject to the same terms and conditions). When combined, these contractual arrangements hold the potential to motivate disparate project teams to work collaboratively for the benefit of the project, incentivising good team performance with open-book transactions and by sharing gain. Because they also share pain, they make it more feasible to collaborate earlier.

The Project 13 initiative aims to do this for the infrastructure sector. It is an industry-led response to delivery models that fail not just clients and their suppliers, but also the operators and users of our infrastructure systems and networks. It seeks to develop a new business model based on an enterprise, not on traditional transactional arrangements. The objective is to boost certainty and productivity in delivery, improve whole life outcomes in operation, and support a more sustainable, innovative, highly skilled industry.

The other route to earlier, better collaboration is by changing business models, probably through vertical or horizontal integration, i.e. creating 'one-stop shops' selling building designs or whole buildings.

Public procurement and MMC

By Trowers & Hamlins LLP

The *Construction Playbook* promotes procurement that 'maximises' investment in MMC by 'adopting longer term contracting'. However, any public procurement strategy to increase use of MMC must also comply with the public procurement regime and, unfortunately, many public sector clients claim that these two aims are incompatible. While inaccurate, the claim is understandable given the complexities of knowing how to apply the Public Contracts Regulations 2015 (the Regulations).

What is procured: supplies or works?

The root of the difficulty is the potential for confusion about what is being procured. For example, if a procurement is simply for the supply of offsite manufacturer materials, the procurement is likely to be classified under the Regulations as a public ***supplies*** contract which, if the total contract value exceeds £189,330 exclusive of VAT, must be publicly advertised on the UK Government's Find a Tender service. A supplies-only contract assumes that a client will get other members of their supply chain to install modules or components fabricated off site.

This supplies-led approach might be appropriate if the client has the resources and experience (either in-house or through existing third-party contractors and consultants) to manage the logistical complexity of the modular build on site and to properly install and monitor the construction of modular units and other offsite components.

Alternatively, if a client wishes to procure a contractor to take responsibility for the design, manufacture, delivery and installation of those units, then it is more likely this would be classed as a ***public works contract*** which, if the works value exceeds the defined financial threshold of £4,733,252 exclusive of VAT, should be advertised.

As a third option, the client could procure a manufacturer directly and select trade contractors to undertake the groundworks and installation and use a construction manager or project manager (or both) to monitor and provide advice in delivering the project. This is likely to involve a combination of supplies, works and services contracts. Correct classification will depend on the primary purpose of works, services and supplies. It may also require a number of linked procurements.

Once the client has decided what they need from the market, the public procurement regime can be harnessed to deliver its requirements in a cost-efficient, quality-driven manner.

Alternative procedures

Clients can standardise design so that manufacturers can work to agreed design standards. This approach simplifies the route-to-market competitive comparison through a faster public procurement exercise using the Open or Restricted Procedures.

More flexible procedures under the Regulations, such as the Competitive Dialogue and Innovation Partnership procedures, as well as design competitions, allow the client to work with a number of tenderers bidding on an output specification. This flexibility allows the collaborative development of a bespoke product.

Publicly procured, compliant framework agreements can also be used for early engagement with framework members (including contractors, suppliers and manufacturers) to develop an outline design for the project. This can then be market tested through a mini competition run in accordance with that framework.

Price evaluation

There is evidence to suggest that, in some instances, with an offsite method of construction (modular or panelised), more cost will be incurred earlier than with traditional build methods (see *Adjusting cost perception* on page 33). Nevertheless, overall feasibility studies carried out on schemes to ascertain viability highlight benefits such as:

- lower life-cycle costs
- earlier revenue from rents and sales
- the financial benefits of a higher quality product and digital record, leading to reduced maintenance costs over the life of the asset.

The trouble is that these benefits are rarely taken into account during a procurement process, even though all are important for clients with a long-term interest in the developed assets.

The Regulations make it clear that life-cycle cost (e.g. non-price elements) of a product, works or service may be taken into account at the point of procurement. Accordingly, clients seeking to evaluate the cost-benefit ratio of an MMC solution versus a traditional build solution need to select a formula for evaluating quality and price that anticipates and incorporates all of the non-price elements (e.g. ongoing costs) of a bid as well as quality and price.

The traditional focus on lowest price under a public procurement process does not take into account life-cycle cost. However, there are price evaluation formulae that do. For example, by adopting an absolute price evaluation model (e.g. a price–quality ratio), a client is able to evaluate the quality and cost elements of a bid on their own merits and ascertain how much quality it is obtaining for the price of the bid, rather than seeking to compare two different methods of construction against each other on a lowest cost basis.

Long-term relationships

Creating collaborative relationships allows lessons to be learned, which helps teams to improve their performance from project to project. The same is true for manufacturing supply chains. Clients who establish them can make efficiencies and improvements through iterative design development and manufacturing practice.

Public procurement is not a barrier to the creation and development of long-term relationships. Framework agreements and longer term contracts set up by clients enable relationships to be developed over time, obviating the need for full procurement procedures on every new project.

As an example, the Framework Alliance Contract (FAC-1) creates collaborative relationships between clients and a series of manufacturers and suppliers, facilitating an integrated supply chain. It is recommended by the Construction Leadership Council as a model form for long-term strategic relationships for MMC and has been adopted by the Crown Commercial Services as its form of contract for its MMC framework.

A number of other clients have also set up contractual and corporate joint-venture arrangements with manufacturers to guarantee reliable supply and take advantage of a collaborative approach to design and product development.

Early engagement

Not only do the Regulations allow and encourage early market engagement, they consider it an essential ingredient to a successful procurement. Clients are encouraged to consult economic operators ahead of a Contract Notice being published, provided that such consultations are used properly and in a commercially sensitive manner and do not subsequently discriminate in favour of a particular bidder or class of bidder. Engagement of this kind helps clients to establish their best procurement option, route to market, detailed specification, approach to risk, contract terms and so on.

Social value

MMC frequently results in less work on site, which is perceived as making it harder to meet any requirements for manufacturers and contractors to add social value locally through training, apprenticeships and employment proposals. This is likely to be a concern for local authorities and registered providers who, as well as responding to the Public Services (Social Value) Act 2012, which measures benefits nationally, may have their own community investment plans that require them to demonstrate benefits from public works locally.

While there is a grain of truth in this perception, it is not a foregone conclusion. MMC does not always result in offsite solutions. Where it does, the factory might be in the region or the project might make use of flying factories nearby. Even if neither is true, it is still possible to offer training, apprenticeships and employment proposals in the region in respect of the on-site works, and clients can ask suppliers to invest in local community benefit schemes.

The Regulations do not need to be perceived as a barrier to embracing MMC. Clients just need to be clear in their MMC objectives, undertake soft market consultation and decide what they are procuring before approaching the market on a formal basis. Frameworks can be used to streamline the process as well using the more flexible procedures to discuss requirements with bidders. Clients should structure award criteria carefully to evaluate bids on quality, social value, life-cycle and sustainability targets.

Note that this text reflects the current Regulations and does not speculate on future changes which might become law following the publication of the Green Paper Transforming Public Procurement.

Adjusting cost perception

There is a perception that MMC leads to higher overall costs. It is generally true that more cost is incurred at an earlier stage, but any such impact is more than compensated by less expense on site, better quality, faster builds, safer sites, easier site management, cheaper finance and better productivity by the time the project is complete – all of which lead to significant cost savings overall. The evidence is growing and the improvements will increase as MMC mainstreams and matures.

It is important to look at a project holistically. A DfMA approach does not necessarily map onto traditional cost plan templates. Durations, risks, what is delivered by whom, what is needed, or not, all play a part. It is clear that a significant proportion of most projects' costs are related to their duration. Reducing project duration creates opportunities for reducing costs.

Independent KPMG research into the cost of MMC in 2016 conservatively estimated that, at the project level, financial net savings of 7% were possible as a consequence of the shortened construction period. These project savings enabled faster rental revenue income and savings derived from avoiding construction inflation costs. Taken together, this equated to £36 million savings on a 50-storey central London office building. The report went on to say, 'In reality, the saving to a commercial or public sector client is likely to also include savings on any interest on loans, improved project predictability, and improved quality'.

Improving quality assurance

Adopting MMC depends crucially upon proper quality assurance. Until then, underwriters' lack of confidence in the systems puts off risk-averse investors (including mortgage lenders), which, in turn, inhibits the adoption of MMC. The insurance industry's reluctance is due to the lack of data on the long-term performance of homes built using MMC, without which it cannot easily assess the risk level of those homes. Unsurprisingly, the issue has reached fever pitch in the aftermath of the Grenfell Tower fire inquiry.

Embedded and maturing standards (such as BS 5606: 1990 Guide to accuracy in building, BS ISO 21723: 2019 Buildings and civil engineering works, modular coordination, BS EN ISO 9001: 2015 Quality management systems and BPS 7014: 2021 Standard for modular systems for dwellings), certification schemes, such as NHBC Accepts and BOPAS (Buildoffsite's Property Assurance Scheme, developed with Lloyd's Register and BLP Insurance), and other initiatives are helping to build confidence. As construction is productised, lessons in after-sales services from other parts of the world (for example, the Japanese system-housing market, where manufacturers offer whole-house warranties to differentiate themselves in the market), abetted by feedback using the Internet of Things (IoT) and from platforms (see *Chapter 6, What will the near future look like?*) could reinforce and inform those standards.

Increasing interoperability

Understandably, building system manufacturers want to maximise their return on investment by protecting their intellectual property (IP). While this might make sense at the level of the manufacturer, it is ultimately counterproductive at the level of the sector. Clients baulk at having their hand forced: deciding to go with IP-protected building systems introduces long-term dependency on just one supplier and closes down options, all of which exposes them to unwanted risks.

One way to avoid being hostage to IP is to procure on the basis of performance specifications and standardising component or assembly interfaces. Another is P-DfMA, which encourages interoperability to a common standard, creating an ecosystem of, for example, interchangeable components, sub-assemblies and pre-assemblies from different suppliers. While clients are still tied to one platform, they nonetheless have choice. For more on this, see *Chapter 6, What will the near future look like?*

Applying mass customisation

Site-specific differences in local planning constraints, historical and cultural contexts, and environmental factors all mean that each site is more or less unique, a fact that has in the past seemed to demand bespoke solutions. This myth is being dispelled by applying mass customisation concepts, which allow tailored solutions using a palette of standardised components, assemblies and façade materials without affecting the cost or time savings associated with offsite manufacturing.

Skills

DfMA is often linked to digitisation, automation and earlier engagement between disciplines, and requires good knowledge of manufacturing processes and logistics to succeed (see *Chapter 5, The impact of DfMA on traditional skills and roles*). However, these new skills are only just entering into the building designers' core curricula of formal training and education. What's more, where the skills exist, they are distributed across many different players – architects, structural engineers, project managers, contractors, suppliers and so on – meaning that very few have an overarching understanding.

Although the educational syllabuses for the traditional disciplines are slow on the uptake, some training providers are beginning to respond. For example, the Bartlett (University College London's school of architecture) has recently set up a post-graduate degree in Design for Manufacture. Elsewhere, the Construction Industry Training Board (CITB) and providers such as the Manufacturing Technology Centre (MTC), Construction Scotland Innovation Centre (CSIC) and the Supply Chain Sustainability School are running courses on offsite skills, which include DfMA. Organisations such as Buildoffsite and the BESA have also published DfMA-based methodologies.

Improving knowledge and understanding

Offsite construction has an image problem that stems from a legacy of false starts going back decades. For example, the postwar prefabs did not perform well and the aspirations of the High Tech movement that followed never bore fruit.

Even today, when the context and technology are radically better, offsite manufactured buildings often seem to conjure up images of unattractive volumetric units stacked on top of each other like shipping containers. This is a far cry from the reality, which encompasses a range of offsite solutions capable of being used to create architectural beauty.

These negative biases work against the uptake of MMC, and operate in all parts of the construction industry, making clients, funders, insurers and consultants less likely to consider it, and architects, engineers and other consultants less likely to propose it or argue the case. Importantly, it makes the end-users hesitate, ultimately affecting returns.

However, the potential of mass customisation, digital technology and standards as a way of enabling MMC to meet increasingly urgent challenges is beginning to dawn on the industry, and the tide is turning. Indeed, in adding DfMA to the default setting for all construction projects, this Overlay will play an important role in promoting the possibilities and value of MMC.

Change management

The full benefits of MMC will only follow the wholesale integration of DfMA as business as usual in construction design practice. The size of this task should not be underestimated: shifting deeply entrenched habits and ways of working will take many years and face jeopardy as it bridges the notorious 'valley of death' that characterises the adoption of innovation.

As we have seen in the UK Government's presumption in favour of MMC, private initiatives to shift the dial and, indeed, the publication of this Overlay, change is already afoot. Design professionals are in an influential position to speed up the catalysis by adopting a DfMA mindset in their regular way of working and giving MMC an equal or greater billing in their thinking as early as possible.

Positivity has the power to affect adoption, as demonstrated by main contractor Kier. For several years a leading light in the promotion of MMC, they choose to focus actively on the positive and to acknowledge psychological or behavioural factors that would encourage take-up.

In the second volume of their *Choice Factory* document, they promote their six-step 'levers of change' as the necessary model for beneficial transformation, with the following recommendations:

1. Make selecting offsite manufacturing an easier choice for everyone, especially clients.
2. Use the same, simple language, starting with the Categories of MMC, and establish recognised standards that enable consistency and assurance.
3. Raise the status of offsite manufacturing across the industry.
4. Make offsite manufacturing the norm by engaging and inspiring design teams.
5. Reward individuals' efforts, engagement and impact.
6. Proactively support and enable education and awareness throughout the industry, including with clients and the supply chain.

CASE STUDY

R7, Kings Cross, London

Date completed: 2017	**Sector:** Commercial offices	**Value:** £70m
Client: King's Cross Central Limited Partnership/Argent LLP		
Architect: Morris+Company and Weedon Architects		
Contractor: Kier		
Manufacturer: Lindner Façades and Walker Modular		
MMC categories used: Categories 2, 5, 6 and 7		

R7 consists of commercial offices, a three-screen cinema, and a retail and restaurant space.

Benefits of the DfMA approach

The offsite-manufactured solution led to a reduced site workforce; simplified construction; less working at height; quality assurance; and cost and delivery certainty.

Kier offered buildability advice throughout Stage 3 and engaged early with suppliers to tailor the design for efficiencies to meet design freeze dates and procurement milestones.

BIM facilitated prefabrication of specialist assemblies and, through visualisations, design communication with the client.

The unitised, flat-pack façade system was installed faster, more safely and with 40% fewer workers than a traditionally built equivalent. Overall, offsite manufacturing accounted for a quarter of the project's build cost.

> Whilst developing this complex M&E design, the Kier team took the whole building's requirements into consideration. This meant establishing a flexible and robust M&E design that met our budget, that solutions were thoroughly considered, and we were able to meet objectives.'
>
> **Symon Bacon**, Project Director, Argent

4

Choosing the best option

Choosing the best option

The business case, feasibility and concept design decision-making processes that lead to MMC offsite manufacturing solutions (and that therefore require DfMA) are similar to those that lead to business-as-usual projects. High-level objectives are balanced against known financial, organisational, legal, market and physical constraints to narrow down options.

There are, however, two important differences: timing and knowledge.

The differences

There is a finite window of opportunity for deciding on DfMA processes that lead to offsite solutions, after which their benefits quickly recede, especially for decisions about the primary structure.

For example, a design predicated on a framed structure will require a lot of design rework (which takes time and costs money) if the designers are asked too late to switch to a solid structure manufactured off site (such as CLT).

As the level of detail in the design increases, it becomes less feasible to switch between different options. This is due, in part, to the technical restrictions imposed by using standardised or repeated components and assemblies but also to the need to freeze the design before manufacture and to accommodate the manufacturer's lead-in times.

Integrating MMC into project delivery

By Hawkins\Brown and AnyOffsite

Whichever form of construction is chosen, it is good practice to ensure that a robust, agnostic optioneering process has been carried out as early as possible. The strategic aims of the project should align with the corporate objectives of the client and the most appropriate form of construction and predominant material should be chosen to meet the clearly defined environmental, social and corporate governance and other project goals. (Different materials will provide different environmental credentials. Some housing association funds set a limit on the number of offsite-manufactured homes, for example.)

Some areas for consideration include production of the technical design stage deliverables, which may need to be brought forward to as early as RIBA Stage 2. A risk register should form part of the early project management processes, which will be differently impacted as alternative forms of MMC are proposed.

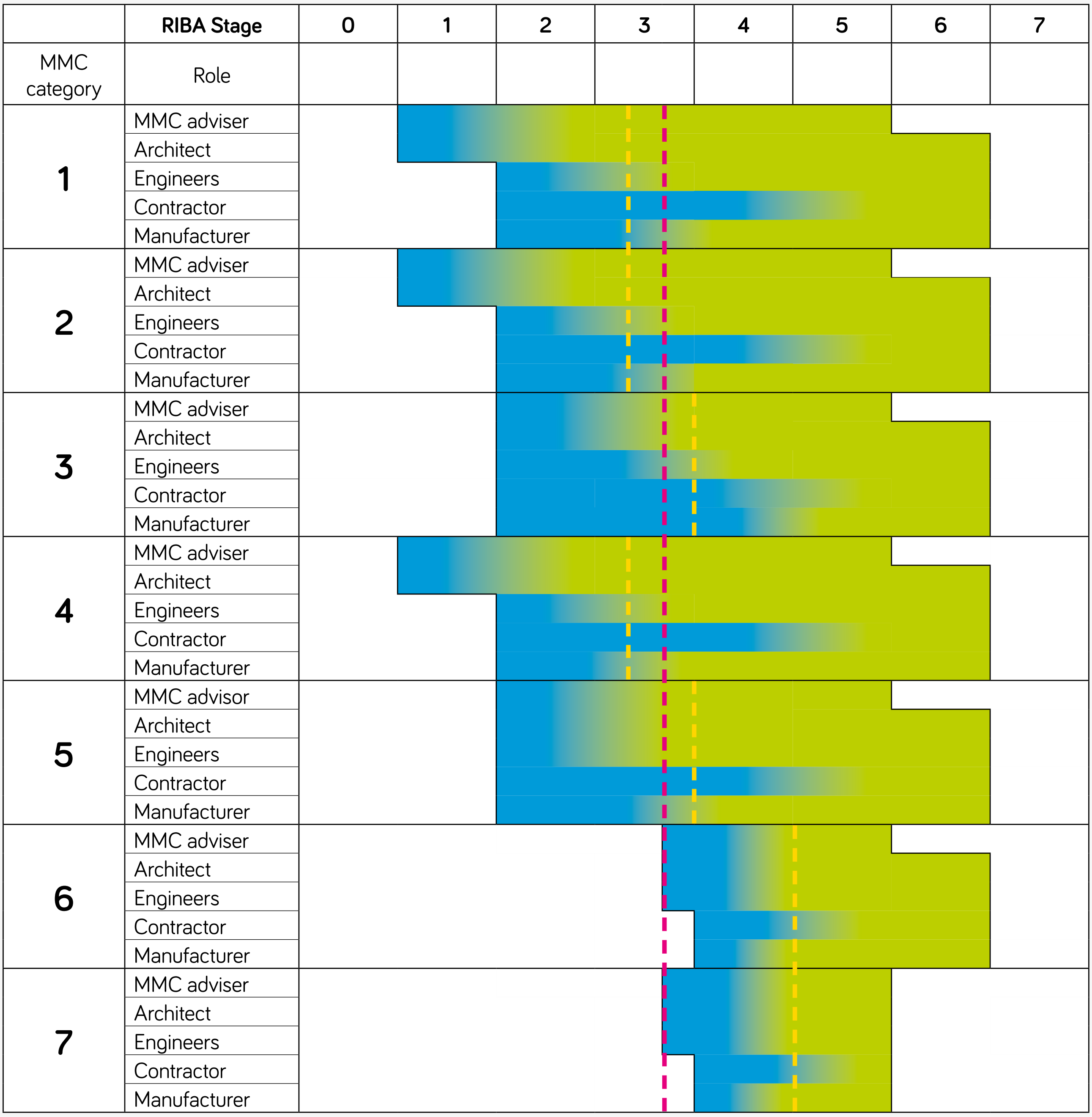
MMC adviser

For the successful implementation of a DfMA approach, the project team should include an MMC adviser who will initially provide optioneering advice to assess which construction method or system best suits the desired outcomes for the project. Their role is to challenge and provide support, as well as advising on the most appropriate supply chain for the project. The role can be undertaken by the architect, if they have appropriate knowledge, or by a separate consultant. It could also be an in-house function of the client, if they have the capability. The MMC adviser can be involved in all RIBA stages but their most important contribution is prior to the appointment of a manufacturer or contractor.

During RIBA Stage 0, the MMC adviser can offer support in setting out project aims and a performance specification, together with defining a procurement strategy. They might also advise on the relative merits of possible construction methods or systems in relation to meeting project goals and the procurement routes available. As a general rule, confirmation of the procurement strategy and understanding of the impact on cash flow of different forms of MMC should be achieved during RIBA Stages 1 and 2.

The MMC adviser could also help to define the level of competence (in relevant MMC categories) needed from design team partners before they are appointed. This advice could then be incorporated into the appointment criteria.

MMC procurement



Organised by MMC category and RIBA Plan of Work stage, the **blue** sections on this matrix show, from earliest to latest, the recommended windows of opportunity for the appointment of members of the project team. The **green** sections represent the typical duration of different parties' appointments.

The windows of opportunity vary depending on the category of MMC being considered. For example, it may be possible to decide on large-format cladding systems (Category 6) as late as RIBA Stage 4, but Category 1 solutions will need to be considered from RIBA Stage 2 to prevent costly redesign and programme delays.

The **pink** dotted line running through Stage 3 represents the town planning application, which may in practice be submitted at any time during Stage 3. The **yellow** dotted line represents design freeze, which is essential for deriving optimum value from using offsite solutions. This is shown in each case as the latest time for fixing the design and fixing it earlier is likely to bring greater value.

Optioneering

The optioneering process should involve the design team and client, with good practice involving a series of workshops facilitated by the MMC adviser. Some of the questions which should be answered at different stages include the following:

RIBA Stage 0

1. **Will the Business Case benefit from reduced programme or higher quality?**
   For example, if the asset will produce income via rental, a shorter programme will improve the return on investment, lower maintenance costs will improve longer term profitability and a higher performance specification will reduce ongoing costs of heating.
2. **Is there a fixed end date for project completion?**
   For example, if the project is providing student accommodation, handover for occupation in September at the start of the academic year will produce significantly greater income than completion in November.
3. **Are there any funding or indemnity implications for a particular specification or method?**
   For example, Homes England currently provide the opportunity for developers and asset owners to apply for additional grant funding if using MMC.
4. **Has a risk register been set up?**
   Note that there are different risks associated with various MMC categories and these should be identified, together with a methodology for managing them, starting at RIBA Stage 0.
5. **Are there any restrictions on design team appointments?**
   For example, does part of the corporate governance insist on appointments from a specific framework where MMC may not be included in the skillset of consultants?
6. **Is there any legislation or governance preventing the use of specific methods of construction or materials?**
   For example, fire regulations need to be carefully considered to ensure the appropriate material is specified. Structural limitations also need to be understood for different forms of construction.
7. **Are the logistical, design or maintenance benefits and limitations fully understood for each system?**
   Having a database of issues which may have arisen during past projects is invaluable in identifying potential challenges for the current project. For example, if MMC Category 1 is being considered, is the road infrastructure adequate for delivering modules and is there space for a suitable crane on the site?
8. **Is this a one-off project or part of a broader programme?**
   One-off projects may not be cost effective for all categories of MMC. If brand identity is important and, for example, an apartment layout will be repeated on future projects, it is worth discussing this as a new potential product family for a manufacturer. Volume needs to be considered, which will vary for each form of MMC and each individual manufacturer.

RIBA Stage 1

1. **Site logistics and access**

   The risk register will help to identify any potential issues, which should be researched more thoroughly before committing to a particular method of construction. Logistics surveys should be carried out by the MMC adviser.

2. **Manufacturing supply chain capacity and capability**

   Some manufacturers are set up only for high volume, while others can offer lower output volumes. Understanding the nuances of the supply chain is part of the role for the MMC adviser. The results of this research may affect the procurement strategy.

3. **Building type suitability**

   Certain forms of MMC may not be appropriate for the project. For example, using line-loaded systems for open-plan areas may not be suitable.

4. **Procurement barriers**

   If the client organisation has strict procurement governance, a specific construction framework may need to be used for certain projects. These frameworks normally do not include MMC manufacturers, in which case a tripartite agreement may have to be negotiated. Note that newer kinds of framework that embrace MMC by allowing the client to engage manufacturers direct rather than through the Tier 1 contractor do exist. (See also *Public procurement and MMC* on page 31.)

5. **Cost, time and quality considerations**

   All these factors will contribute to the MMC assessment. Sustainability should form a significant part of any project evaluation, which should be balanced with best-value metrics, such as those published by the Construction Innovation Hub or Construction Leadership Council. The *Construction Playbook* is a good reference.

6. **Are any sustainability improvements achievable through choice of delivery?**

   Embodied carbon and reduction of waste should be considered as part of the DfMA process.

7. **Digital strategy**

   Collaboration across the design team will improve productivity, which should be filtered through to the construction and project management team. If the client organisation is able to take advantage of the benefits of implementing a digital strategy, such as the UK BIM Framework, then the facilities management (FM) team should be involved in decision-making at the outset.

8. **Handover strategy**

   Planning the handover in line with the digital strategy is key to taking advantage of the benefits offered by digitisation. Digital twins can be created to provide FM teams with access to product data, assuming the technology is available and the teams are trained in the use of the software.

9. **Design team appointments**

   Choice of the design team may be limited, subject to the client organisation's procurement governance. Appointment of the design team should be based on experience of the form or forms of construction being considered following discussion with the MMC adviser.

10. **Specialist manufacturers and suppliers**

    Depending on the procurement choices, it may be appropriate to introduce the MMC supply chain of specialist manufacturers as part of the tender process. The MMC adviser will be able to introduce an appropriate choice of suppliers and manufacturers for the different methods of construction being considered, and a competitive exercise can be run separately or as part of the construction tender.

RIBA Stage 2

1. **Spatial Constraints?**

   The Architectural Concept design should be created based on an agnostic choice of construction method but in such a way that the MMC categories are considered. Care should be taken to ensure that the design can be substituted for an alternative form of MMC if necessary. An important point to note is that different forms of MMC can be combined to create the spatial layout and achieve other design objectives.

2. **MMC category optioneering**

   Consider:

   a. typology and structural span
   b. sector/sub-sector
   c. potential for repeatability
   d. building height
   e. size of scheme – too small/too large?
   f. planning height restrictions, which may restrict storey heights, for example. (Category 1 floor build-ups are typically deeper than those using traditional systems.)

3. **Site ground conditions**

   It is possible that different forms of MMC will require different types of foundations, with some construction methods offering lightweight options which may prove beneficial for different ground conditions or for use as a rooftop extension, for example.

4. **Procurement**

   The Procurement Strategy should be finalised at this point and engagement with the MMC supply chain should commence. There are a number of ways to engage. If it is a public procurement exercise, then using the negotiated and competitive dialogue process might be a good option.

5. **Manufacturer availability and factory capacity**

   The MMC adviser should be able to liaise directly with the supply chain to ensure that any interested manufacturers will have factory capacity to deliver according to the programme. Early decisions can have a very positive impact on the success criteria for each MMC project.

RIBA Stage 3 onwards

During the early phase of RIBA Stage 3, the final decision should be made on which form of construction should be used for submission of the planning application and, ideally, a manufacturing partner appointed – if not already part of the design team. If a positive planning outcome is considered likely following the pre-application process, technical designs can be brought forward during the planning determination period. If a contracting partner has not already been appointed, competitive tendering can take place in the usual way.

Assuming any client-led procurement regulations allow for this and the different forms of contract have been discussed and agreed between all parties during the initial procurement discussions, the MMC adviser should be able to provide a database of contractors skilled in the chosen form of construction. Public clients can use an existing framework or consider a streamlined competitive dialogue process to allow the design solution to be discussed.

Appointment of the construction team should involve the MMC Adviser, who could be novated as part of the agreement, if appropriate. This ensures continuity and increases the likelihood of a successful project outcome. Note that the need to novate can be avoided under alliancing forms of contract.

Following handover, a Post Occupancy Evaluation should be conducted to gauge user feedback and provide a higher level of understanding for future projects.

Set out on the right foot

The main challenge is to get MMC on the radar, not just as an also-ran among the business-as-usual favourites but as a genuine contender for best option, as follows:

- Give MMC an equal billing to traditional building approaches at Stage 0, long before the design team has been selected, and thereafter keep it firmly on the agenda.
- Instead of only looking at the downside risks of MMC and upside of traditional approaches in the appraisal, properly feature the downside risks of traditional approaches (time on site, health and safety costs, weather delays and so on) alongside the considerable upside benefits of MMC.
- Commit to procurement strategies that incentivise collaboration and allow timely engagement with people with the right knowledge.

The objective should be to consider options with the benefit of all the information in time to get the best solutions (see *Integrating MMC into project delivery* on page 39).

Effect on cash flow

Committing to different procurement strategies has consequences for project cash flow because it frontloads the costs of design fees and, if the project gets that far, pre-contract services agreements and offsite manufacture.

Without specialist knowledge, this could make the appraisal difficult to support. Global project management consultancy Faithful+Gould, however, advises that this frontloading is worth it, given the right knowledge, experience and set-up. As they put it, capital build costs can be 'very competitive when compared to a traditional build'.

Powers to influence

If engaged early on, design team members who understand the DfMA process can influence procurement decisions. By embracing a DfMA approach, they are more likely to be able to see the potential for MMC and thus advise on the decisions that would best support their realisation.

Even if engaged later, the window of opportunity to extract value using MMC may not have passed, and design team members can still sway the conversation and, in turn, educate not just their clients but also investors, funders, insurers, development appraisers and cost consultants, even if only retroactively, as lessons learned.

Buildings are always a mix of MMC and traditional build and so even if the window of opportunity closes before every MMC option has been explored, it does not necessarily matter. There is still potentially value in applying at least some MMC options.

Site conditions

There are times when the choice of building method is narrowed. For example, if the site and ground conditions are known to require lightweight construction then a timber-framed building becomes a strong candidate, which promotes timber genres of offsite solutions up the list of options.

Other physical characteristics of the site and access routes will help to narrow down options too. Very tight access roads that are unsuitable for large lorries will preclude Category 1 MMC volumetric options, whereas tight sites with little on-site storage (but good road access) will do the opposite.

Clients' requirements

Equally, the client's requirements, e.g. for sustainability, health and safety, quality or speed on site, might only be achievable with MMC options. A new school building that must be built during the summer holidays in time for the new academic year, for example, could very easily mean that MMC options trump traditional ones. Many clients have operations that must be protected from construction-related impacts. Again, DfMA can help to achieve this.

CASE STUDY

The Grange University Hospital, Llanfrechfa, Cwmbran, South Wales

Date completed: November 2020 **Sector:** Healthcare **Value:** £350m

Client: Aneurin Bevan University Health Board

Architect: BDP

Contractor: Laing O'Rourke

Manufacturer: Laing O'Rourke and Bennett Architectural

MMC categories used:

- Category 2: structural façade panels incorporating architectural outer skin, insulation and load-bearing inner skin ready for decoration with factory-installed windows.
- Category 3: precast columns, structural twin walls, lattice planks, hollow-core planks and Peikko DELTABEAMs®.
- Category 5: volumetric bathroom pods, multi-service risers and horizontal service modules, prefabricated integrated plumbing system assemblies, plant skids, pre-assembled and pre-wired air handling units, flue structures, chiller pipework modules, boiler flue assembly and modular wiring.

The Grange University Hospital is a 55,000 m^2 specialist critical care centre with 470 inpatient beds for people across Gwent in need of highly specialised services. It was delivered through the collaborative Designed for Life Building for Wales framework programme.

Benefits of the DfMA approach

A DfMA approach identified that significant project efficiencies were possible using MMC. In the event, the project was delivered 23% faster than an equivalent traditional programme. It was handed over with zero defects, significantly within budget, and opened four months ahead of schedule, in time to support the battle against the second wave of Covid-19.

> The Grange University Hospital environment not only provides amazing modern facilities for patient care but has opened so many opportunities to the Health Board in relation to recruitment of staff wanting to come and work in this state-of-the-art building.'
>
> **Nicola Prygodzicz**, ABUHB Executive

The critical data and project management issues

Early collaboration and design freeze

Notwithstanding the structural challenges outlined above, the objectives of DfMA remain the same. If an offsite option has been selected, the design must be frozen not just before construction work begins but before manufacture to avoid rework on site. Success still depends on early collaboration between designers, contractors, manufacturers and suppliers, and on having the time and opportunity to resolve and coordinate various design inputs to a high level of detail comparatively early.

This contrasts with what happens on more traditional projects, where project team partners come together later, and designs can and do continue to evolve right up until (and sometimes after) the part of the design in question is actually being built, which, of course, is bad practice.

One of the key principles of successful DfMA is the extent to which design teams are integrated (see *Chapter 5, The impact of DfMA on traditional skills and roles* for more on this). It is worth noting that the inability to enable early collaboration is one of the key barriers to overcome in promoting the uptake of offsite construction (see *Chapter 3, Market readiness*).

Lead-in times

Offsite manufactured solutions must be pre-ordered for timely delivery to site and so the lead-in times are important considerations for the project schedule. The more complexity and pre-assembly involved in the solution, the longer the lead-in time needed, usually.

Design automation

The value of DfMA has the potential to be greatly increased by automating design as far as possible. This includes using automated configuration, customisation and optimisation tools, and reusing verified or validated virtual 3D objects, all to speed up design work without compromising quality assurance.

Pre-manufacturing verification

Since it is important to get the manufacture right first time, it pays to invest in pre-manufacturing verification and systems engineering control.

It is standard practice to use 3D digital design and visualisation tools to detect clashes, simulate the functioning of various systems or strategies, prepare virtual walk-throughs and, for critical components and assemblies, to experiment with physical prototypes before freezing the design.

It is less common to have formal systems engineering oversight to manage changes and derogations efficiently, although this 'integrator' role (see *Chapter 5, The impact of DfMA on traditional skills and roles*) is common in manufacturing and is beginning to appear on offsite construction projects. Needless to say, the need is urgent: it is critical that the interfaces between on-site and offsite elements are coordinated and that any changes on either side are only implemented if compatible with the other.

BIM workflows

With many design disciplines having to sign off on designs for offsite manufacture, the value of DfMA is greatly improved by operating with 3D digital models in a common data environment with protocols for data management bound by agreed standards. Having this 'one source of truth' spoken in a common language limits the overall amount of rework and smooths the collaboration necessary for successful outcomes.

Knowledge management for continuous improvement

The successful development of DfMA techniques requires that organisations learn from past experience and use the intelligence to improve their design systems. This includes continuously adding to and improving libraries of virtual 3D objects, and fine-tuning and extending customisation, optimisation and configuration design code. See *Chapter 6, What will the near future look like?* for more on this.

The critical design considerations

A DfMA process entails all the usual design considerations typical of construction projects. However, several become especially critical:

Connections

Connections on site between proprietary offsite-built systems and either other offsite systems or traditionally built parts of a building might not function and could even compromise design intent and compliance. To avoid unsatisfactory on-site workarounds, connections therefore require careful upfront design consideration and verification.

This difficulty is one of the key drivers of the Platform Design Programme (see *Chapter 6, What will the near future look like?*), which hopes to establish standards that allow quality-assured interoperability and open up the market so that clients are not bound to just one proprietary system.

Tolerances

With offsite-manufactured solutions built separately and only coming together later, they cannot so easily be adjusted to fit unanticipated on-site conditions. Thus, dimensional and other kinds of accuracy – such as accounting for possible post-build movement (e.g. thermal expansion in building services pipes penetrating structural elements) – become more important. Note that tolerances should not be so fine that components or assemblies become difficult to manufacture; a happy balance must be achieved.

The flip-side to this is just as important: the traditionally built foundations or anchor points for offsite manufactured solutions must be able to accommodate them without rework. The quality of on-site workmanship becomes even more critical than usual, which can be helped by a range of digital measurement tools.

Variety

The fewer the number of variations in repeated components, sub-assemblies and pre-assemblies, the greater the efficiency gains. Minimising variety reduces time and cost of specification, ordering, manufacturing set-up and assembly. Of course, this should not be at the expense of the head client's business case, brief or the project's long-term value.

Spatial coordination

In a DfMA process, standardised offsite-manufactured solutions are king and so designers should look for opportunities to rationalise layouts to suit the solutions' needs. For example, pre-assemblies (such as bathroom pods) with in-built services optimised to interconnect vertically should, wherever possible, be stacked vertically.

Ease of assembly and/or commissioning

Since the objectives of DfMA include reducing the amount of on-site labour (especially skilled labour, which is in short supply) and time on site, the offsite solutions should be designed for safe, simple and foolproof assembly and/or commissioning, with particular attention to the interfaces or connections between offsite solutions and other structures. A typical objective, for example, is to build without the need for scaffolding.

Ease of maintenance, repair, modification, disassembly and/or decommissioning

Designers should consider issues arising from the offsite solutions' service lives in the context of the needs of the asset of which they are part, where such consideration adds value for the head client and can be justified in the business case.

Thus, if the design life of the asset is 60 years but the solution's is less than that, the solution should be capable of being maintained, repaired, upgraded or replaced viably, and the supply of parts should be reliable. Equally, once the solution has served its design life, it should be capable of being reused, repurposed or recycled and not end up in landfill. Obsolescence planning is required, particularly as heating and cooling systems evolve and more electronics are integrated into buildings.

The critical logistical issues

Distance from factory to site

Project partners and clients should weigh in the balance the distance between the factory and the site. The more distant the factory and the more international border crossings involved, generally speaking the less viable and reliable the supply line and, of course, the higher the offsite solutions' cost and embodied carbon.

(Note that this is not always the case. For example, precast concrete is cheaper to produce in some countries, in part due to different tax systems (e.g. on aggregates and corporations), wage rates and so on.)

Sequence of manufacture

Suppliers of solutions manufactured off site should consider the best sequence of manufacture for the most efficient production process. This may differ from the best order of delivery to site and assembly, which could affect schedules. Lean manufacturing should be linked to the order in which the customer needs to receive it. Manufacturers that minimise changeover time and cost can work efficiently with very low batch sizes.

Sequence of assembly

Contractors and designers should also consider the best sequence of assembly, and thus delivery to site, bearing in mind the overall construction plan, the solutions' vulnerability to damage in transit and the limits of safe on-site storage. It is generally considered most efficient if the offsite solution is delivered using just-in-time logistics, for assembly straight off the lorry, without any period of on-site storage.

CASE STUDY

Kitchener Barracks, Chatham, Kent

James Newton

Date completed: 2021	**Sector:** Residential	**Value:** £50m
Client: TopHat		
Designer: TopHat		
Contractor: TopHat Communities		
Manufacturer: TopHat Industries		
MMC categories used: • Category 1: volumetric modular system		

The Kitchener Barracks housing development will deliver 302 volumetric homes and apartments on the site of a former 17th century barracks in the Brompton Hill conservation area of Chatham.

Benefits of the DfMA approach

TopHat's DfMA approach is standardised and their modular output factory controlled, allowing them to minimise embodied carbon and achieve excellent airtightness in the finished buildings, which also incorporate triple glazing, PV and MVHR technologies.

TopHat's homes embody as little as 729 kg of carbon, while they achieve airtightness levels as low as 0.85 $m^3/hr/m^2$.

With volumetric modules manufactured off site, assembly on site is comparatively quick, limiting disruption at this sensitive site.

> 'This project has been instrumental for us in challenging preconceived ideas on manufactured housing. We believe that MMC is not just reserved to flat contextless sites and characterless identikit architecture, but that it can deliver beautiful, contemporary and highly sustainable homes and places, within sensitive conservation contexts, and even on complex constrained sites.'
>
> **Krishan Pattni**, TopHat


James Newton

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The impact of DfMA on traditional skills and roles

CHAPTER FIVE

The impact of DfMA on traditional skills and roles

As we have seen, DfMA involves changes in the knowledge needed, the people involved, the extent of collaboration and the timing of their collaboration. It also involves the use of new digital modelling and verification tools in BIM workflows to automate design – where doing so adds value.

Against this background, it is inevitable that:

- individuals with qualifications in traditional industry disciplines will need to acquire new skills and change their behaviours
- project teams may need to create new roles and organise their collaboration differently
- organisations may want to rethink how they can best offer their services, possibly by integrating vertically (i.e. from initiation through to asset management) or horizontally (i.e. putting all the design disciplines under one roof) or both
- organisations may also want to think about what is known as longitudinal integration, i.e. how they set up feedback loops for continual improvement to deliver better value over time.

Exactly how this happens and what it means will emerge and crystallise over time as DfMA is embedded more thoroughly into the construction and procurement landscape. Every service provider has its own unique set of strengths and weaknesses, challenges and opportunities, and so how they respond is uncertain and likely to be varied.

New skills, knowledge, behaviours and roles

A DfMA approach is an evolution of business as usual rather than a wholesale revolution. Most of the professional skills acquired at university, in training and on the job remain relevant.

However, the Construction Leadership Council recently surveyed the additional needs of the sector as a whole in its *Industry Skills Plan for the UK Construction Sector 2021–2025*. It identified 'skills for a modernised industry' as one of several challenges, highlighting the following among their priority areas:

- skills for smart construction and net zero
- digital transformation
- skills for repair, maintenance and improvement
- collaborative skills.

These areas include the following gaps:

Productising skills

As DfMA leads to repeated uses of the same outputs, the ability to turn them into standalone products is becoming increasingly valuable. Architects and manufacturers already do this by creating component libraries of virtual BIM objects that help to speed up design, especially combined with algorithms that allow mass customisation. To succeed, actors will also need to understand intellectual property, and how to market and price their products.

Computer coding and data science skills

Design automation for configuration, optimisation and customisation needs increasing levels of computer coding skills as the algorithms that underpin these processes take account of efficient manufacture and allow mass customisation. On the assumption that solutions have generic value, these shortcuts are already being packaged into rules-based design systems that designers can use without high-level coding skills.

Information management skills

Although 3D computer modelling and BIM are widely used across the industry, the underlying protocols and management standards (enshrined in the BS EN ISO 19650 series) have yet to be used accurately. This matters because having a common language prevents large amounts of rework and duplication of effort and improves collaboration. The UK BIM Framework recently published the desired 'Learning Outcomes', while the Construction Innovation Hub has issued a directory of training providers who can help to achieve them.

The National Digital Twin Programme has also published a Skills and Competency Framework supporting the development and adoption of an Information Management Framework and the National Digital Twin (see *Chapter 6, What will the near future look like?*). It identifies the need for a whole raft of new roles in data management, from cyber security specialists and data architects to process modellers.

MMC optioneering skills

The skills for undertaking processes and using tools for selecting MMC options are currently patchy across the industry, with some pockets of excellence amid the more common lack of knowledge. The more quickly the industry can add knowledge about the weighted pros and cons of the available options based on real-world feedback loops to its core bodies of professional knowledge, the better the success of MMC, the faster its adoption and the sooner client bodies and ordinary citizens will benefit.

Improving knowledge in this area should tip the role of MMC adviser into the mainstream (see *Integrating MMC into project delivery* on page 39).

Manufacturing knowledge

Because the construction industry has been, until now, a complex system for making bespoke assets, its boundaries have stopped short of manufacturing. Inevitably, the accompanying bodies of relevant professional knowledge do not include manufacturing knowhow, with the consequence that design does not properly anticipate manufacturers' highly influential cost drivers. The push to adopt MMC makes the continuation of this knowledge deficit untenable. Manufacturers need to make this information available, and designers need to understand how to use it to optimise value.

Collaboration behaviours

Removing the barriers to better collaboration will require considerable behavioural changes for an industry used to transactional, adversarial contractual relationships. Understanding the 'in it together', outcome-focused incentives of new models advocated by the *Construction Playbook* and in vertically integrated alliances will mean unlearning many ingrained biases and habits.

Integrator roles for systems engineering

As manufacturing expertise is added to the complex construction system, it has the potential to have unforeseen consequences that benefit from active management and coordination. In recognition of this reality, the 'integrator' role advocated by the Project 13 initiative, which is essentially a systems engineering function, is beginning to emerge as best practice.

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What will the near future look like?

What will the near future look like?

Leaders in the UK construction industry published a vision for the future of the built environment in April 2021. It sets out the shared, sector-wide ambition to align industry outputs to desirable global outcomes (i.e. the UN Sustainable Development Goals). In particular, it acknowledges the built environment as a complex 'system of systems' comprising built, natural and so-called 'cyber-physical' systems.

They say that enabling this vision will take two major shifts:

1. **New business models** for better interdisciplinary integration, not just between traditional built environment actors but also with government, academia and, crucially, the users of the built environment, which add value by affording better collaboration.
2. **Improved digital capabilities**, including in systems engineering complexity science, information management and data science, which are all necessary for DfMA, and **improved digital tools**, including the Internet of Things, artificial intelligence, connected digital twins (see below), virtual reality and robotics, all of which help variously in automation, driving PMV and validation.

New business models

The UK built environment vision is already being implemented through the Government's *Construction Playbook*. As its policies take hold, the built environment will be increasingly motivated to industrialise its processes, which will further dismantle the remaining barriers to adopting DfMA and MMC.

In particular, business models developed exclusively to deliver one-off buildings procured in the traditional way will be under pressure to change.

The Transforming Construction Network Plus group produced an essential guide about business models, which it defines as 'the way a firm creates value, and captures a portion of the value for itself'. It warns that, because of existing organisations' 'dominant logic', they may find it hard to change their business models. Nonetheless, they should consider doing so if:

- there is an unmet or changed demand in the market
- a new solution opens the market to new customers previously excluded from the market
- new technologies emerge that reshape value delivery (e.g. the internet)
- they need to fend off competition, often from low-cost producers or
- there is a rapidly changing competitive environment, for example, from a focus on cost to one on life-cycle carbon impacts.

The convergence of global challenges and technological advances, along with the policies in the *Construction Playbook*, creates most of these conditions.

The Association for Consultancy and Engineering has recently completed work on what this might mean for the future of consultancy (including architects and engineers). They agree that traditional consultancy business models have evolved to generate returns on people-hours rather than investments in technology, and that change is needed. As they say, this will open up 'huge opportunities to better understand performance across the whole investment lifecycle and to use this insight to provide greater value to clients.'

They predict that consultancies that sell a blend of traditional outputs with ones that supply ongoing performance (i.e. that are focused on outcomes) – in sales aftercare and building system monitoring services with mass-customisable designs or products, for example – will become the norm. With adequate attention to protecting intellectual property, this creates an income stream to justify the upfront investment in R&D needed to create robust products.

Improved digital capabilities and tools

The digital capabilities needed to thrive in the DfMA era are set out in *Chapter 5, The impact of DfMA on traditional skills and roles*. In summary, they include competencies in automation, data science and data management, most likely using the BS EN ISO 19650 series of standards for managing information over the whole life cycle of a built asset using BIM.

The most significant tools on the horizon are platforms, which incentivise the creation of families of interoperable tools and/or products accessed through a single digital portal.

Again, the Transforming Construction Network Plus group has produced essential plain-English guidance. The concept of platforms is best defined by referring to examples: Google and Apple have technological platforms; mobile devices are advertising platforms; consoles are gaming platforms; and manufacturers use product platforms. Either closed (i.e. for in-house use only), semi-open (for you and your supply chain) or open (for your ecosystem), they all share the following features:

- a set of core assets (components, processes, knowledge, people, relationships) that don't change much
- a complementary set of highly varied peripheral components
- a stable interface between the two that encourages innovation.

The platform types most directly relevant to DfMA are the product and ecosystem platforms.

Product platforms

The product platform type has three generic variants that allow mass customisation:

- **Scalable:** a core product's design parameters can be varied in way that opens up the market.
- **Modular:** a family of products with a core set of features and probably a standardised interface design to which interchangeable peripheral modules can be added to create different products with almost no impact on production.
- **Generational:** a set of design rules that allow new generations of products to be made without having to start from scratch.

The new OpenBuilt platform, announced in April 2021, is an early and as yet under-developed example. Describing itself as an 'integration hub', it claims to offer access to 'a wide library of pre-integrated applications from trusted companies' to help 'innovate and drive more efficient, sustainable and safer construction projects'.

Ecosystem platforms

The ecosystem platform is described as 'a hub of value exchanges, coordinating buyers and sellers through complementary assets, services, and technologies'. In the context of the construction industry, this has exciting potential for joining up different software tools.

Many architects are already using this kind of platform when they design using Revit, for example. Whether they acknowledge it or not, their designs are co-created through, in this example, the Autodesk ecosystem platform, which takes its share of the value generated in the form of a licence fee.

Platform-based DfMA

The Construction Innovation Hub sees the value of an open platform for extracting maximum value from DfMA – called platform-based DfMA, or P-DfMA – and so is, through its Platform Design Programme, marshalling the industry to develop a platform construction system aligned to open versions of the models described above. Indeed, this programme is central to the Value Toolkit.

Ultimately, the P-DfMA system will identify features, such as floor heights and structural spans, that are common to different types of building and can be standardised to make a generic kit of parts. The idea is that these parts will be manufactured to common parameters, making them easy and intuitive to assemble in countless ways – enough to realise any architectural ambition.

The Programme's Defining the Need report gives more detail. Applying systems engineering and manufacturing techniques, it plans to 'develop, prototype, test and demonstrate a platform design and delivery concept that can:

- Be implemented at scale across a pan-government pipeline of social infrastructure works.
- Reduce cost, delivery time and lifetime carbon emissions.
- Boost productivity and increase the asset whole-life value.
- Offer an opportunity to integrate active renewable energy systems'.

To help develop the idea, the Programme will set rules 'to enable (as a minimum):

- Interfaces and interoperability, to encourage competition and resilience;
- Consistent and reliable governance, to foster trust in the multi-sided market; and
- Implementation detail, to make platforms easier to use reliably'.

National Digital Twin

Allied to this, the Centre for Digital Built Britain, which is part of the Construction Innovation Hub, is researching the idea of a National Digital Twin. Part of the cyber-physical system underpinning the Vision for the Built Environment, it is conceived as a series of interconnected digital assets that can improve how infrastructure is built, managed, operated and decommissioned for the public good. The system has the potential to provide asset performance feedback that can be used to improve DfMA and MMC.

Glossary

Term	Definition
Categories of MMC	A definitional framework for categorising the many outputs of MMC in the residential sector (see *Categories of MMC* on page 16). It was developed by the UK Government's Ministry of Housing, Communities and Local Government's Joint Industry Working Group on MMC for improving communication and understanding in the mortgage finance, insurance and valuation communities. It is proving useful in other sectors too.
Component library	A store of ready-made digital representations of physical modules, assemblies or components encoding relevant information that can be used in a BIM process. The information typically consists of both geometric representations and associated data tables at different levels of detail for use at different project stages. Their value is in the fact that they can be reused to speed up design. Some component libraries are developed in-house by design teams for particular projects or clients. Others are generic, produced and maintained by product manufacturers or CAD software developers.
Construction industrialisation	The process of adopting more manufacturing practices, including specialised tooling, mechanisation and automation, to make the construction industry more efficient and productive, with better quality assurance for better-value, more reliable and more sustainable long-term outcomes. See also MMC.
Continuous improvement process (CIP)	A formal system for improving the quality of products, processes and/or services continuously over time. 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 Poka-yoke (a Japanese term for mistake-proofing assembly operations). Manufacturers generally aspire to achieving 'Six Sigma' levels of performance to obtain high production yields of products with many components.
Design for maintenance	A formal process for ensuring that maintenance and intended service life is factored into the design process to reduce whole-life costs. It can include the use of smart components, i.e. ones that are equipped with sensors and are linked to the Internet of Things in a way that allows them to be monitored and controlled.
Design for manufacture and assembly (DfMA)	DfMA is a formal design approach that focuses on designing for ease and efficiency of manufacture and assembly. It is a prerequisite for considering modern methods of construction, especially offsite solutions. It extends the business-as-usual focus of building design to resolve designs in terms of how efficiently they can be manufactured and assembled on site.
Field factory	A temporary factory facility set up near to the construction site to manufacture modules or pre-assemble flat pack components before assembly on site. The work carried out in them counts as offsite construction. They can also help with transportation logistics.
Flat pack	A term to describe prefabricated assemblies that are transported to site as flat, 2D elements as opposed to volumetric 3D units. They trade speed of on-site assembly for transport efficiency.
Flying factory	See Field factory.
Hybrid construction system	Any construction system that combines two or more categories of MMC.
Interface	The point at which two or more components, sub-assemblies or systems connect or interact. Interface characteristics may be physical or performance-related, and provide the necessary functions of the interface. Interfaces are the focus of standardisation to allow interoperability, thus opening the market up to competition from different manufacturers.

Term	Definition
Interoperability	A characteristic of a product, component, assembly or system, whose interfaces are completely understood, which allows it to work with other products, components, assemblies or systems, at present or in the future, in either implementation or access, without any restrictions.
Just-in-time logistics	Planning to ensure that deliveries arrive on site only when they are needed, thus avoiding the overheads and added risks involved in on-site storage, improving overall build efficiency.
Kit of parts	A system of separate proprietary parts manufactured off site, conceived to be efficiently assembled on site. The rationale for keeping the parts separate is to allow more efficient, safer handling and transportation, and to allow flexibility (within certain constraints) in their final configuration.
Lean	An adjective used in industry to describe processes where waste (of materials, time, cost, handling, intellectual property and so on) has been eliminated or minimised, so improving efficiency and productivity.
Mass customisation	A process that allows manufacturers to customise products by varying production processes without affecting their ability to charge low (i.e. mass-production) prices (see *Tailored products at low prices: mass customisation* on page 10).
Material handling design	The detailed planning of the packaging of components and assemblies manufactured off site and the logistics of getting them to their final destination on site, with the objective of making the process as efficient as possible. It can result in incorporating physical features on the components, assemblies or their packaging, including lifting points or positioning aids to facilitate handling or assembly.
MMC adviser	An individual or organisation with the necessary knowledge of the MMC systems and the manufacturing industry to assist the client and the design team in assessing which construction method or system best suits the desired outcomes for the project and to provide guidance in the procurement process.
Modern methods of construction (MMC)	Building methods designed to improve productivity and safety or reduce the need for labour, or both. They have the specific objective of improving efficiency compared to business-as-usual techniques. Whereas the term is most commonly associated with volumetric offsite construction, it actually includes many other outputs, including on-site process innovations. The most widely used definitional framework is the Categories of MMC (see *Categories of MMC* on page 16), which, while useful, omit the concept of platforms (see *Chapter 6, What will the near future look like?*).
Modular construction	A process that allows manufactured components to be configured in multiple ways by exploiting standardised interfaces.
Near-site factories	See Field factory.
Offsite construction	A collective term for construction processes that are carried out away from the building site in a way that adds value compared to business-as-usual construction. Offsite construction can happen in a factory or in a specially created temporary production facility close to the construction site (see Field factory).
Platform-based design for manufacture and assembly (P-DfMA)	The process by which designers develop and make use of platform construction systems to create new bespoke built assets.
Platform construction system	A suite of quality-assured, interoperable engineered components (products or sub-assemblies), governed by a rulebook specific to that system, that can be designed to integrate in predefined ways to create functional buildings for specific purposes (e.g. schools, hospitals, accommodation and so on).

Term	Definition
Pre-manufactured value (PMV)	A proxy measure of project efficiency calculated as the project's gross capital cost less the cost of prelims (site overheads) and site labour, divided by the gross capital cost, expressed as a percentage. The business-as-usual benchmark is 40%; anything higher has more of its operations conducted off site. (See *Measuring the benefits* on page 12.)
Process control and monitoring	A formal system of statistical controls and standardised procedures to ensure that the journey from design to construction is consistent and repeatable, thereby assuring quality and reliability. Production is monitored and variations plotted between control limits which, if exceeded, trigger corrective actions before critical limits are reached.
Standardisation	In the context of DfMA, standardisation involves quality-assured systems and processes that govern design, manufacturing and assembly inputs with the objective of improving the reliability, speed, consistency and efficiency of digital and physical outputs, making it possible to achieve economies of scale. With CIP, the extent of the benefits is refined over time.
Sub-assemblies	Major building elements that are manufactured off site, potentially comprising a combination of components. Examples include walls, floors, roofs, balconies, balustrading assemblies, façade cassette panels and pre-assembled M&E elements.
Supply chain	A generic term describing the contractually linked people and companies who supply the services, materials, parts, components and equipment that are used to make larger components, assemblies and whole buildings for a head client.
Supply chain integration (SCI)	A process for improving the efficiency and effectiveness of the supply chain's performance by setting the conditions for cooperation and collaboration. When successful, supply chains run projects safely, quickly and without rework, and deliver the client's requirements for quality and reliability on time and on budget.
Volumetric	An adjective describing large-scale assemblies constructed offsite in such a way that they enclose a 3D volume of space. In the context of MMC, the term tends to be restricted to assemblies that incorporate primary structural elements, i.e. that fall into Category 1 of the Categories of MMC.

DfMA Overlay to the RIBA Plan of Work, 2nd Edition

The second edition of the DfMA Overlay Template embeds DfMA processes into the RIBA Plan of Work 2020.

It should be understood in the context of its accompanying report and used to supplement guidance in the *RIBA Plan of Work 2020 Overview*. In particular, capitalised terms in the Overlay are defined in the Overview's glossary.

The DfMA Overlay is an additional Project Strategy within the RIBA Plan of Work and a companion to the Construction Strategy.

It sets out the tasks that are necessary to achieve a successful DfMA approach on a project and to effectively implement the many modern methods of construction.

The tasks are to be undertaken by the project team after having been distributed among the client team, design team or construction team as appropriate under professional services or building contracts.

It has the following task bars:

Stage Outcome

The stage outcomes are high-level statements of the core outcomes to be expected at the end of each stage. These are taken from the RIBA Plan of Work 2020 Template.

Core DfMA Tasks

These identify the core DfMA tasks that should be completed during each stage to ensure the successful implementation of modern methods of construction throughout the project life cycle. The lists are high-level summaries of the tasks that are neither exhaustive nor chronological.

Suggested Digital Tasks for DfMA

These additional tasks support the delivery of a DfMA approach through the use of digital processes and tools to improve efficiency and embed data-driven decision-making, aligned to the UK BIM Framework.

Described as 'Suggested BIM Tasks' in the first edition, this class of tasks has been widened to include all relevant digital processes, including data use, visualisation and digital infrastructure outside of the project information.

Procurement Strategy

The Procurement Strategy task bar identifies the key procurement decisions within the RIBA Plan of Work structure for different standard procurement routes. The tasks are taken from the RIBA Plan of Work 2020 and enhanced by prompting key actions necessary for effective implementation of the different MMC categories.

Key changes compared to the first 2016 edition of the DfMA Overlay

The key changes in this new edition are listed below.

- The Stages, Stage Outcomes, Procurement Strategy and defined terms have been updated to match the RIBA Plan of Work 2020.
- The tasks associated with the MMC categories have been incorporated and the necessary procurement tasks associated with each category identified.
- The BIM tasks have been expanded to include wider digital processes and use of data.
- Platform approaches (see *Chapter 6, What will the near future look like?*) and the delivery of programmes of projects that pertain beyond a single project timeline have been recognised. These approaches can impact the design stages of a project by creating key Stage 5 level information before a project begins.
- The tasks associated with delivering an effective asset handover and early feedback on delivery of DfMA approaches and use of MMC have been added.
- The reuse and recycling considerations of pre-manufactured products at the end of an asset's useful life have been included.

DfMA Overlay to the RIBA Plan of Work

The MMC categories

Category 1: 3D primary structural systems
Category 2: 2D primary structural systems
Category 3: Non-systemised primary structures
Category 4: Additive manufacturing
Category 5: Non-structural assemblies and sub-assemblies
Category 6: Traditional building product-led site labour reduction/productivity improvements
Category 7: Site process-led site labour reduction/productivity/assurance improvements

Construction Strategy

A strategy that considers specific aspects of the design that may affect the procurement, buildability, manufacturing, assembly or logistics of constructing a project or that may impact health and safety aspects.

The **Construction Strategy** comprises items such as the craneage strategy, site access and welfare accommodation locations, reviews of the supply chain and sources of materials, and specific buildability considerations, such as the choice of frame (steel/concrete/timber) or the installation of larger items of plant.

Projects span from Stage 1 to Stage 6; the outcome of Stage 0 may be the decision to initiate a project and Stage 7 covers the ongoing use of the building

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
Stage Outcome at the end of the stage	The best means of achieving the **Client Requirements** confirmed If the outcome determines that a building is the best means of achieving the **Client Requirements**, the client proceeds to Stage 1	**Project Brief** approved by the client and confirmed that it can be accommodated on the site	**Architectural Concept** approved by the client and aligned to the **Project Brief** The brief remains 'live' during Stage 2 and is derogated in response to the **Architectural Concept**	Architectural and engineering information **Spatially Coordinated**	All design information required to manufacture and construct the project completed Stage 4 will overlap with Stage 5 on most projects	Manufacturing, construction and **Commissioning** completed There is no design work in Stage 5 other than responding to **Site Queries**	Building handed over, **Aftercare** initiated and **Building Contract** concluded	Building used, operated and maintained efficiently Stage 7 starts concurrently with Stage 6 and lasts for the life of the building
Core DfMA Tasks	Developing a programme-level platform will follow Stages 0–4, concluding in a library of systems to technical design level information and the use of these systems on a project will provide significant optimisation of Stages 1–4 (Stages 0–4)							
	Consider opportunities for applying the seven MMC categories across portfolios or programmes of projects Consider how DfMA might impact on the **Business Case** or **Client Requirements** including repurposing of a building and reuse or recycling of components at the end of the building's life Consider how different MMC strategies might impact the set up of the project team	Initiate DfMA thinking including opportunities for repeatability of elements on future projects and consider how to incorporate the seven MMC categories into the **Project Brief** and **Project Programme** Undertake **Research and Development** with manufacturers to determine supply chain capability prior to design commencing Consider DfMA solutions when undertaking **Feasibility Studies** considering best practice DfMA exemplars from comparable projects Consider how different MMC categories impact the set up of the project team including the **Responsibility Matrix** and professional services contracts including intellectual property issues	Embed appropriate MMC categories into the **Architectural Concept** Identify DfMA solutions to **Sustainable Outcomes** in the **Concept Design** Ensure that the **Cost Plan**, **Construction**, **Sustainability**, **Plan for Use** and **Health and Safety Strategies** consider DfMA, liaising with supply chain as required Consider **Strategic Engineering** aspects including floor-to-floor heights, spans, space requirements and foundation design Consider early discussions with the planning and transport authorities to safeguard the **Architectural Concept**	Update the **Construction Strategy** and the **Cost Plan** taking into account discussions with potential contractors and the supply chain Consider buildability, including how the erection sequence, fabrication or manufacturing techniques and tolerances impact on interfaces in the **Construction Strategy** Check warranty provision for the proposed MMC systems	Consider how DfMA impacts on **Building Systems** including 'plug and play' connectors and interfaces Develop the DfMA components more accurately considering interfaces and specifications including structural, water/moisture/vapour penetration and acoustic issues Consider prototyping and other methods of quality assurance Consider manufacturing and assembly risks in the updated **Health and Safety** and **Construction Strategies**	Update the **Construction Strategy**, including a logistics plan, considering lifting, handling and transportation for each component and sub-assembly Monitor quality of offsite manufacturing Consider **Commissioning**, optimising the use of factory acceptance testing	Provide **Feedback** on defects and how these might be avoided on future projects Provide **Feedback** on the DfMA process for consideration in future projects	Consider any **Feedback** during the in-use stage necessary to inform future projects Monitor the performance of standardised components including maintenance and replacement and provide **Feedback** Provide **Feedback** on what aspects have been identified for reuse or recycling at the end of the building's useful life and how the building can be adapted rather than demolished
			Technical design activities may commence in Stage 2 in order to verify DfMA concepts (Stages 2–4)					
Suggested Digital Tasks for DfMA	Analyse data, including cost and programme, from previous DfMA projects in order to set benchmarks	Use BIM for the preparation of **Feasibility Studies** Consider using or establishing a digital library including DfMA objects and components and how this may be used across multiple projects Confirm **Information Requirements** (or Exchange Information Requirements (EIRs) under the UK BIM Framework) including Asset Information Management (AIM) requirements and develop BIM execution plan	Develop digital information including data rich DfMA content possibly from a digital library of Stage 4 ready objects Validate the model against the **Information Requirements** Consider DfMA tolerances in the development of the BIM model Use digital tools and technologies including VR to improve client experience	Update digital information including data rich DfMA content possibly from a digital library of Stage 4 ready objects and consider impact on **Final Specification** Validate the model against the **Information Requirements** Use digital tools and technologies as part of coordination exercises including 4D (time)	Update digital information including information from supply chain Validate the model against the **Information Requirements** Use 4D technologies to scenario test and rehearse the sequencing set out in the **Construction Strategy**, including manufacturing, logistics and assembly, before work starts on site	Use tools and technologies to train site operatives and access digital information including setting out, method statements or product manuals Use digital technologies to track manufacturing, packing, logistics and delivery process Use digital tools to compare actual against planned progress on site and to inspect **Construction Quality**	Ensure digital information relating to DfMA components is linked to **Feedback**, including lessons learned and potential repurposing	Consider configuration management techniques to update digital **Asset Information** during the life of the building Consdier use of **Digital Twin** and smart building technolgies aligned to Internet of Things and cloud technologies to obtain data from in-use activities

Procurement Strategy

ER Employer's Requirements
CP Contractor's Proposals

	0	1	2	3	4	5	6	7
Traditional	Appoint client team including MMC adviser (all routes)	Appoint design team (all routes)			Tender; Appoint contractor			Appoint facility and asset management team, and strategic advisers as needed (all routes)
Design & Build 1 Stage					ER; CP; Appoint contractor			
Design & Build 2 Stage			ER	Pre-contract services agreement	CP; Appoint contractor			
Management Contract/ Construction Management			Appoint contractor					
Contractor-led			ER	Preferred bidder	CP; Appoint contractor			
MMC Categories 1, 2 and 4	Ensure client team has the requisite knowledge of MMC and DfMA in order to deliver the best solution (all MMC categories)	Review possible subcontractors and consider manufacturers and how they relate to contractor appointment (Stages 1–4)						
MMC Categories 3 and 5			Consider specialist subcontractors and any constraints and embed into design (Stages 2–4)					
MMC Categories 6 and 7					Low impact on procurement			

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Core RIBA Plan of Work terms are defined in the *RIBA Plan of Work 2020 Overview* and glossary and set in **Bold Type**.

Further guidance is included in *'Mainstreaming DfMA in Construction'*

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