Offsite construction – concept design and delivery

A collaborative research report from Buildoffsite and CIRIA

Publisher

Buildoffsite is a membership organisation with members from a wide range of UK and international client, supply, professional services and academic organisations.

Buildoffsite is a UK-based business organisation that promotes:

- Increased use of offsite methods across all sectors of the UK construction market.
- Innovation in the development of offsite solutions.
- More effective promotion of business and project benefits by offsite solution suppliers.
- Improved understanding by clients and suppliers of the benefits of offsite solutions.
- Education and skills development in the use of offsite solutions.
- Debate, discussion and knowledge transfer relating to the use of offsite solutions.

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A permanent, positive, transformation of the UK construction industry – enabled through the increased adoption of offsite and pre-manufactured solutions to drive increased productivity.

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Our work addresses industry issues, challenges and opportunities to provide business and delivery improvement. We work collaboratively across the construction industry to identify good practice, develop new approaches and to identify and enable innovation.

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Summary

This guide aims to help clients and their advisors understand the benefits and how they can deploy modern methods of construction (MMC). It will be of particular use to those using offsite methods in their projects and programmes across their asset portfolios.

A range of subjects are considered from a strategic perspective, including net zero carbon and other sustainability aspects, while providing many practical tips, guidance and case studies. It is designed to be complementary to existing industry guidance and both national and international standards.

This guide covers infrastructure and buildings aspects of construction, which may both benefit from the advantages offered by offsite solutions. It provides insights into the different categories of MMC and how they may be specified. It addresses aspects relating to whole life cost and whole life carbon, including the social cost of carbon. Guidance has been provided for project planners and specifiers, to facilitate project delivery using offsite methods and avoid unintentional outcomes of actions that may create barriers to exploiting the benefits of offsite construction.

There is a lot of innovation happening in the construction sector at this time, so the guide has considered how intellectual property may me managed and new innovations brought to market, with a section describing the evolution of assurance schemes, which can be key to gaining market acceptance.

Procurement processes are also evolving, which should facilitate the adoption of offsite solutions. More clients are requiring the delivery of digital twins for their facilities. This guide explains how inter-operable digital twins may add value and how offsite solutions can help make this happen.

The ultimate aim is to equip readers with the knowledge needed to develop procurement plans and concept designs in ways that enable the efficient implementation of offsite and other modern methods of construction.

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Executive summary

There remains the need to transform construction, to address productivity, cost, balance of trade and climate change issues. Consequently, there is an increasing demand for the use of moden methods of construction (MMC) and in particular, forms of it which employ offsite methods and a high level of pre-manufactured value (PMV). This is particularly evident in the UK public sector, but is not limited to that.

There are a wide range of benefits associated with using offsite solutions, along with a different range of risks to be managed.

The MMC category definitions in wide current use in the UK are based upon construction methods for the residential sector. These categories need expanding to fully reflect the opportunities and types of MMC being used in other sectors, in particular for infrastructure.

Before considering individual projects, there are significant advantages for the strategic application of offsite methods across portfolios and programmes of projects and, from a product developer's perspective, across market sectors.

Whole life cost is becoming increasingly important in decision making. Offsite solutions have a range of opportunities to offer in this context. Both from the perspective of reducing project duration and cost and with respect to opportunities to develop more robust and continuously improving designs for in use performance. A range of methodologies exist to evaluate this but the offsite sector needs to collect more data to convey the complete picture.

The climate crisis means that we cannot ignore the whole life carbon challenge. Construction projects are increasingly being evaluated against carbon targets and benchmarks. Methodologies for evaluating embodied and whole life carbon are continuing to develop but are already usable. The increasing focus upon the social cost of carbon for public sector projects will probably open up opportunities for the offsite sector, as innovations, such as new materials, are easier to introduce through their incorporation into products (sub-assemblies, assemblies and systems) than they may be through the application of traditional specifications and standards. This is likely to be assisted by an increasing use of performance-based specifications and standards.

It is important that clients and specifiers do not, unintentionally, specify their requirements and designs in such ways as to limit the application of MMC, and in particular, offsite methods. A key to this is gaining insight into MMC, the cost drivers and constraints early in a project, either through early engagement of specialist manufacturers or contractors, or by employing specialist consultants. It is important that this is considered before planning applications, Development Consent Order (DCO) applications, Transport and Works Act 1992 applications or similar are submitted. There are numerous ways of incorporating flexibility into requirements and designs that would enable both MMC/offsite and traditional approaches to be offered at the tender stage(s) but it is easy to over-design before considering how to exploit MMC/offsite.

Planning a programme or project is significantly different when incorporating MMC/offsite. To achieve major cost savings, approaches that significantly reduce overall duration need to be considered. Integration and coordination of onsite and offsite works is critical to realising the benefits. Factory lead times, and the availability of the necessary lifting equipment with capacity, need to be understood early on in the planning process along with supply capacity, rate of supply and logistical challenges. The concept of 'design freeze' is significant as factory-based systems have strict rules concerning the introduction of design changes. Products designed for factory assembly are designed to a more detailed level than traditional construction, along with the process for manufacturing them, which makes it difficult and costly to make changes once released for manufacture. Cost plans contain different elements and have different risk profiles. The planning of a project's cash flow will also be different.

There is more innovation happening than in the past and with the development of platforms and low carbon technologies this is expected to increase further with the need to address the net zero challenge for the sector. There are opportunities to collaborate and to develop new intellectual property (IP), however, background IP ownership needs to be acknowledged and viable business cases need to be developed, with protection for new IP. Designers and contractors need to understand what is becoming available and how to exploit it. This will require attendance at trade fairs, conferences, and Continuing Professional Development (CPD) sessions and monitoring the trade press, publications and journals combined with methods of sharing information within organisations. Suppliers will also need to market their new capabilities effectively.

Innovations often face barriers to market adoption. Buildoffsite identified this challenge early on in its existence and has collaborated with Lloyds Register Quality Assurance (LRQA), BLP Insurance, the Royal Institution of Chartered Surveyors (RICS), and banks and insurers to develop the Buildoffsite Property Assurance Scheme (BOPAS). This is now being extended to include an assessment of digital maturity (BOPAS+). Other schemes are also available. Rigorous assurance processes are required to help the industry to transition to a more productive, safe and low carbon sector.

In the face of this need for transformation, numerous initiatives have been taken to create more collaborative forms of contracts, such as those establishing longer term frameworks and the Institution off Civil Engineers (ICE) Project 13 (for infrastructure). Design for assembly tends to combine parts. For example, a floor cassette may include structure, ducting, a finish, even a ceiling below it and not require a screed. The latter incorporates aspects of systems engineering, which can be key to the successful incorporation of offsite solutions into projects. It is important to understand the basis of design when developing procurement strategies and cost analyses.

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The national context

1

MMC are, by definition, evolving over time. Within MMC, the proportion of a construction programme or project which is created offsite is increasing, through continuous improvement and innovation, to achieve shorter delivery timescales, productivity, safety and enhanced product quality control. However, numerous other factors are now driving this trend – including the need to reduce the embodied and operational carbon of the built environment and the aspiration to capture the 'golden thread' of facility-related data and information facilitated by new enabling digital technology.

The UK Government, in particular, is encouraging the sector to use more offsite approaches to construction. This is evident in its Construction Playbook[(1)], the Transport Infrastructure Efficiency Strategy (TIES)[(2)] aimed at implementing the Infrastructure and Projects Authority (IPA) policy document transforming infrastructure performance: roadmap to 2030[(3)] and the New Hospital Programmes (NHP)[(95)]. The Ministry of Justice, Department for Education and the Department of Health have been pursuing similar approaches for custodial educational and healthcare buildings for some time. One result of this focused support has been the establishment of the Construction Innovation Hub (CIH) and its focus upon the development of construction 'platforms', which may meet the needs of multiple sectors. The CIH has also championed the development of a Value Toolkit[(4)] to help identify what represents client and societal value and how a construction project may best respond.

Table 1 provides a list of reports which support the uptake of MMC – including offsite.

In addition to government support, the private sector is also seeking to create assets that provide high value propositions, for the same reasons. However, there remain challenges for clients and specifiers when it comes to initiating projects in ways that help to accelerate to uptake of best use of MMC and ensure that they will deliver high-quality assets that represent value for money.

Both the public and private sector recognise the need to address the climate crisis and deliver on their own plans for achieving 'net zero carbon' outcomes within challenging timescales. There is growing evidence that MMC, and offsite methods in particular, are playing an important role in achieving this, as illustrated by the case studies and examples provided in this guide.

This guide sets out to help address the challenges in the areas indicated by the chapter headings. It breaks them down into a range of topics, which have been considered by experts who are tackling them in practice. It provides guidance for clients and specifiers to reduce or remove barriers to using more MMC and offsite content in their projects, without eliminating market competition. The guide also aims to contribute to stimulating innovation in both the product and procurement process domains.

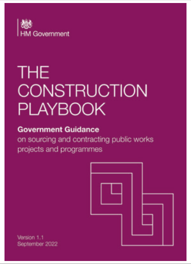
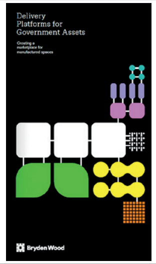
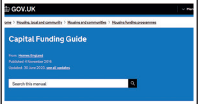
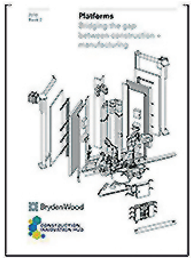
2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
									OSHA OFF-SITE HOMES ALLIANCE DFMA Advanced Manufacturing + Process Management
									
• 33% reduction in the initial cost of construction assets • 50% reduction in: ○ the delivery of assets ○ built environment greenhouse gas ○ the trade gap between total exports and total imports for construction products and materials	• Think modular standardisation • Use prefabrication • Build minimum (design to value) • Maintain a life cycle perspective • Strengthen scenario planning • Optimise engineering processes and choices • Focus on quality • Minimise waste	• Standardised and repeated components • Digital technologies and data within value chain • Front-leading and cost-conscious planning • Strategic workforce planning, smart hiring, enhanced retention • Mutual standards across industry • Cross-industry value chain • Actively managed and funded project pipelines	• Reshape regulation • Rewire contracts • Rethink design • Improve procurement and supply chain • Improve on-site execution • Infuse technology and innovation • Re-skill workers Government to work with the sector to equip the next generation of construction workers with new skills.	**Focus area 1:** Delivering new economic infrastructure improving outcomes for people and nature **Focus area 2:** Place-based regeneration and delivery **Focus area 3:** Addressing social infrastructure using a platform approach **Focus area 4:** To achieve 50% reduction net zero emission across retrofit assets by 2050 **Focus area 5:** Optimising the built environment	The definition framework identifies the following seven MMC categories: **Category 1:** 3D primary structural system. **Category 2:** 2D primary structural systems **Category 3:** Non-systemised structural components **Category 4:** Additive manufacturing **Category 5:** Non-structural assemblies and sub-assemblies **Category 6:** Product-led site improvements **Category 7:** Process-led site improvements.	• Develop organisational strategies to aggregate demand to drive MMC • Engage with the wider supply chain, set realistic targets and ensure capacity and capabilities within the market • Meet and contract for the standards set out by the ISO BIM framework • Consider using platforms	• To smooth the way to achieving the transformation as set out in the Construction Playbook[1] and Value Toolkit[4] • To respond to and strengthen the safety of buildings in line with Dame Judith Hackett's review[96] • Assist the sector in overcoming long standing and well documented shortcomings in productivity, labour performance and risk • To respond to global trends such as climate, air quality, biodiversity, natural habitat, and the availability of natural resources etc		• National construction framework for volumetric (Cat 1) and panelised (Cat 2) MMC to support housing associations and local authorities to deliver off-site homes • Objective to develop 10 000 homes per year by upgrading MMC technology and methodologies • Greater collaboration across the GLA • Reassess organisational structures to adapt to new paradigms in housing delivery • Formalised risk sharing framework • A senior professional lead with responsibility for providing strategic oversight and system leadership over housing delivery within the GLA

Table 1 Reports encouraging the uptake of MMC (courtesy TfL/Mott MacDonald

Why use offsite and what are the benefits?

2

Nigel Fraser, Buildoffsite, with contributions from Nick Hacking, Sheppard Robson, Bernard Williams, IFPI

There are some clear advantages in using offsite construction methods. The benefit realised tends to be a function of the degree to which offsite manufacturing (OSM) (which may be measured as PMV) is used. At the low end of the scale, with limited use of OSM, there is greater risk of potential benefits being lost due to other events affecting the project plan. At the high end of the scale, where most of the project is delivered using OSM systems, with good integration and control of the time and physical interfaces with onsite works, the benefits can be very significant.

Examples in this context:

- **Low scale** – structural frames, small sub-assemblies and 'pods' for spaces such as bathrooms.
- **Intermediate scale** – plant rooms, services risers/distribution, major volumetric modules.
- **Large scale** – use of a complete offsite building system (eg a multi-storey car park, hotel or student accommodation) or 'platforms' that may be configured for a wide range of archetypes.

A range of benefits have been identified, including:

- **Cost benefits** (whole life costs are discussed below).
- **Time benefits** can be both direct and indirect in nature – it is important to understand what represents value to the client:
  - a shorter project may enable a business to open or expand sooner, a school to increase capacity in time for the new academic year or a health service to respond to a pandemic
  - the client's requirements are less likely to change.
  - less scaffolding, welfare and other 'preliminary' costs incurred.
  - less weather-related risk.
- **Quality benefits** of offsite construction from design to delivery with more detail, coordinated tolerances and less rework.
- **Waste**. A significant amount of waste in the construction sector is associated with the need for snagging and resolving issues towards the end of a project during commissioning and handover phases. There are several ways in which offsite enables improvements in quality. These include:
  - design for error-proof assembly (in the factory and at onsite interfaces)
  - easier to design for efficient use of materials
  - easier to ensure that the right tools and jigs are available at the right time and place
  - assembly in controlled factory conditions
  - test, calibration and pre-commissioning in factory conditions
  - easier assurance of airtightness during assembly processes.

- **Health and safety.** The Health and Safety Executive (HSE) has studied accident rates in traditional construction and factories and concluded that moving more construction into factories would reduce accidents overall.
- **Environment**. The reduction in waste has already been mentioned. Factory control systems tend to make it easier to calculate and monitor environmental performance and minimise embodied carbon; a key aspect which is growing in importance as more governments and clients place a financial value on the carbon profile of projects. At the time of writing, the UK, USA and EU have done this and are increasingly requiring business decisions to take whole life carbon into account.
- **Social value**. The Supply Chain Sustainability School's in-depth review of offsite and social value(10) highlights a wide range of benefits and some challenges. The main benefits here relate to:
  - working conditions
  - diversity in the workplace
  - up/multi-skilling the workforce
  - supporting regional growth.

As a general rule, for low scale the offsite elements generally need to be on the critical path for shortening a project to have a significant impact on the project cost overall. They are, however, likely to bring other benefits in terms of quality, whole life, environmental and social affects.

For large scale projects, where families of standard products, specifications or platforms have been developed, productivity is high and time savings can be in the order of a 50% reduction in project duration and a more refined and tested design can underpin delivery of the whole life performance of the resulting asset.

This approach can be extremely beneficial when considering a portfolio of similar projects, where there is an opportunity to prototype such concepts and then deploy them consistently, learning and improving with each iteration as has now been demonstrated across a number of estate portfolios.

It is helpful to employ the same design and commercial consultants throughout such projects to ensure that a strategic approach is followed, with appropriate assurance and insurance. If not, there is a risk that follow-on design and procurement decisions will progressively compromise the strategic intent. The evolution of open standards for construction platforms should reduce this risk.

The recently revised BS 5606:2022(5) provides guidance on integrating offsite and onsite works. The approaches outlined in this standard are key to ensuring that the potential benefits of using offsite methods are not lost when the products are brought to site.

The evolution of benefits assessment

Over the last two decades, several methodologies have been developed to assess the benefits derived from taking work offsite[8].

In 2001 Loughborough University, with funding from the Engineering and Physical Sciences Research Council (EPSRC), developed an evaluation tool for comparing traditional and offsite builds – the Interactive Method for Measuring Pre-assembly and Standardisation Benefit in Construction (IMMPREST).[6] It has previously been used by Buildoffsite to create detailed business case studies. The tool has a simple dashboard and provides a range of criteria for such assessments.

The IMMPREST dashboard includes sections relating to:

- cost
- time
- quality
- health and safety
- environment
- people.

In 2013, Buildoffsite completed a comprehensive review of the sustainability aspects of offsite. Offsite construction: sustainability characteristics[7] covered social, environmental and economic characteristics. In its conclusions it stated:

> *"Offsite construction has many attributes to commend it from a sustainability point of view. The arguments presented in this report are overwhelmingly positive; indeed, it is difficult to find any aspect of offsite construction which has a negative implication for the sustainability case."*

A more recent report from CIRIA/Buildoffsite and the University of Cambridge, Methodology for quantifying the benefits of offsite construction[8] provides a basis for measuring offsite benefits. Metrics relating to project impacts were considered for:

- direct impacts (eg cost, time, quality, labour requirements, health and safety)
- broader impacts (eg environmental considerations, life cycle considerations, local disruption)
- wider societal impacts (eg workforce quality of life, community benefits, industry benefits).

Chapter 5 of that guide provides a range of metrics for evaluating these, while acknowledging that some have not routinely been assessed in the past.

Even where metrics are assessed for a specific project, they are often at the tender stage or for the outcome of the approach used. Comparative data on a like-for-like basis is scarce (eg considering the statistical variability from the tender to completion for different delivery methods). Clients, commercial advisers and main contractors are encouraged to adopt the recommendations made in that report.

Buildoffsite member IFPI has also developed an evaluation tool CombiCycle, a ‘whole life sustainability and cost prediction program’, which includes the ability to make early-stage assessment of alternative construction approaches.[9]

Bernard Williams of IFPI reports that *“it is now in the due diligence phase of version 7”*, which *“incorporates a detailed analysis of door and window openings which are actually a very significant factor in terms of productivity, especially onsite, the analysis of which is essential to a valid comparison between traditional and offsite construction solutions.”*

Case study 1

CombiCycle in whole life cost analysis and prediction

The CombiCycle web-enabled whole life cost and sustainability programme has now been adapted for off-site application, the additional research and programming was sponsored by Buildoffsite and part-funded under a UK government funded innovation programme.

The model is designed to be used at feasibility stage and onwards enabling customers and their designers to see the capital and whole life cost and sustainability implications of potential design solutions from the outset.

In the model each component is given a predicted life expectancy based on typical performance data. However, there is a sub-programme which allows the user to make adjustments for factors that might put the predicted life at risk, eg quality of installation/commissioning, location in the works, manufacturing standard and maintenance regime.

Offsite solutions generally produce more favourable life expectancy, and the model depicts the potential differences compared to traditional solutions. It can also demonstrate the likely extra cost implications of bringing the life expectancy of traditionally installed components up to the level of those installed offsite; more frequent life cycle replacement means more embodied carbon and frequent trips to waste disposal sites.

GIA: 300 M^2 - **Location:** Wales			
Cost Centre	**Default**	Select Survey **Default volumetric_16.12.15**	Select Survey **Default volumetric_16.12.15**
Viewing Result Totals			Filter Element
Quality	Average	Average	Average
Cost Analysis Period	30 Years	30 Years	30 Years
Capital	£ 494,668	* £ 487,558	* £ 487,558
Life-cycle replacement	£ 176,052	£ 177,785	£ 177,785
Maintenance	£ 277,564	£ 279,584	£ 279,584
Cleaning	£ 28,299	£ 29,615	£ 29,615
Energy (in occupation)	£ 569,483	£ 569,509	£ 569,509
Waste Disposal			
Demolition			
Whole Life Total	**£ 1,546,066**	**£ 1,544,051**	**£ 1,544,051**
Whole life sustainability factors (show/hide)			
Sustainability rating			
Initial sustainability	**5.7**	**5.9**	**5.9**
Sustainability Rating	B	B	B
Replacement sustainability			
Time on Site			
Time on Site (weeks)	23.9	9.3	9.3
* Includes saving in Preliminaries		15,374	15,374
**Includes waste materials adjustment - CO2 (embodied Initial) Tonnes		0	0

Figure 1
Results screen

CombiCycle for prediction of carbon emissions in manufacture and in use

The offsite adaptation of the CombiCycle whole life cost and sustainability model produces an embodied carbon count for every component in a building and adds them up to give a value for the building as a whole. The values are also expressed per m^2 of the gross internal area so that the embodied carbon in a design can be benchmarked against best performance in the user's portfolio and in more general databases.

The web-enabled model predicts the energy consumption of the building plant and equipment as well as heat generated by the occupants. It also knows the U-values of each element of a building built up from the k-values of each component in the enclosure modules and calculates the energy and carbon in use on an annual and whole life basis – or over any period of years.

Estimates of energy leakage based on the efficiency (or otherwise) of the construction process are included for each building analysed. Again, components installed offsite under factory-controlled conditions are less prone to accidental heat gain/loss compared to traditionally built alternatives and the model can demonstrate this graphically.

Importantly, these calculations are available at the early stages of design before designers have become committed to what may prove to be less efficient components, systems and installation processes.

The trend in such assessments has been to take a wider range of benefits into account, starting with the capital cost, time and quality basics and increasingly incorporating whole life, environmental and social benefits.

Most recently, Buildoffsite has contributed to the Supply Chain Sustainability School's Social values tools report,[10] which also broadens the understanding of benefits (and challenges) associated with using offsite methods.

A different, overall reduced risk profile

A project with a high offsite content has a different risk profile from a traditional build process and assumptions need to reflect this when planning and costing a project. Examples of the differences could include:

Reduced risks

- Financial
  - cost overruns
  - time overruns

- more standardised operating procedures and work instructions
- re-work and snagging
- Natural (including physical constraints and/or logistics)
  - exposure to weather conditions
  - need for large spaces for materials handling and welfare facilities (potentially controlled by others)
- Human
  - impacts on adjacent business operations and neighbours
  - design is more detailed at start of construction
  - dependence upon skilled trades and the availability of site labour
  - safer working environments.

Potential risks (and mitigation suggestions)

- Financial
  - Dependence upon a single source of supply – insolvency/poor performance (or use open standards/systems/platforms plus rigorous commercial checks, including lower tier suppliers, step-in rights)
- Natural (including physical constraints/logistics)
  - Will it burn/flood/contribute to the magnitude of any damage caused? (Use of well tested and accredited products and systems, photographic records of fire stopping component installation).
  - Transporting large items, eg volumetric and large 2D cassettes/panels (minimise requirements for accompanied loads, check load/bridge heights and junctions on routes).
  - Availability/lead times of high-capacity lifting systems, if needed (book well in advance).
  - Wind impact on lifting schedule (design to minimise risk).
  - The creation of more joints that may become susceptible to water ingress in future, eg precast concrete structures (incorporate enhanced corrosion protection into potentially vulnerable locations).
- **Human**
  - Managing onsite-offsite interfaces becomes critical (apply configuration management/BS 5606:2022).
  - Will it integrate with existing structures? (Review provenance and relevance of prior test plans.)
  - Resolving responsibility/liability questions/durability/insurances (and use of BOPAS/established platforms/products developed in advance of projects).

- Skills – understanding data management, digital twins, offsite and the need for cultural change (education and training).
- Lack of understanding of the basis of design (ensure it is documented and shared with the wider team).
- Social value being removed from the project locality (eg the *Social value tools report*,[10] which addresses this and a range of social benefits and challenges).
- Getting building control sign off.

On the last point, care should be taken in the design and specification of certain elements of MMC to ensure they have the appropriate test certifications, approvals and warranties in place. Complications can arise where systems are combined to meet a specified performance, ie a lightweight metal wall system and an independent dry-lining system will need to be tested together as a single system to ensure it meets the required fire performance. Where the MMC system is new to the market the knowledge and confidence in performance and interaction with other elements will often be lacking so a comprehensive suite of tests and certification will be valuable in avoiding delays while on site.

Case study 2

An approach taken by BAA to exploiting offsite and MMC, incorporating Design for Manufacture and Assembly (DfMA) and lean construction methodology

BAA developed a toolkit (**Figure 2**) where a holistic benefits assessment was the starting point. Getting contracts aligned with the strategy was critical to following it through and realising the benefits. This approach is described in detail in *An offsite guide for the building and engineering services sector*[11]. jointly published by BESA and Buildoffsite. Although written for the building and engineering services sector, much of the guidance is applicable more widely. It defines design for manufacture (DfM) and design for assembly (DfA) into several actionable activities. (Note that this methodology was shared with Buildoffsite and BESA/B&ES by Heathrow Airport Ltd for the publication.)

Figure 2
A representation of the approach developed by BAA (courtesy WOMCL)

The basis of the design strategy needs to be communicated to the wider project team.

The commercial strategy needs to be aligned with the design intent to ensure that the benefits are realised in practice.

Example 1

Seismic platform

Planned outcomes claimed for a platform-based approach:

- *"A 47% improvement in whole life value compared to traditional construction methods".*
- *"A 75% reduction in time to deliver the project compared to traditional onsite construction, and 35% quicker than 3D Volumetric MMC construction".*
- *"A 70% reduction in whole life carbon emissions, through reduced waste, improved building heat and energy performance and the recyclability of the components".*
- *"An 80% reduction in the number of Health & Safety incidents, compared to projects built using traditional techniques, with much of the build taking place in specialist manufacturing facilities".*

From *MMC Best practice case study 1: Seismic design for manufacture and assembly*(12)

Example 2

Assembly of façades on constrained sites

Royal Winchester House in Bracknell, an apartment building that was built in a busy shopping precinct which was open during all of the construction period. The façade being extremely close to the site boundary and the passing public.

Figure 3 Enabling construction very close to the site's boundary (courtesy Euroclad Group Ltd)

Example 3

Delivery of multi-functional modules on a constrained site

The building at 122 Leadenhall Street in the City of London used a construction logistics route which passed through the building, taking minimal space on site. The module in the image was equipped with ancillary fittings such as safety fencing at ground level before being lifted into position by a crane positioned on the tower.

Further information may be found in the BESA/Buildoffsite guide.[11]

Figure 4 Reducing work at height while minimising the site area required for logistics (courtesy WOMCL)

Example 4

Low carbon alkali-activated cementitious materials (AACMs) concrete used for pre-casting products

Several manufacturers are now producing AACMs which may be used to make concrete for pre-casting. Products such as foundation piles, tunnel ring segments and other products may benefit from their beneficial performance characteristics. Aspects such as resistance to chemical attack and fire contribute significantly to reducing embodied carbon for a project. An offsite approach may facilitate this through the use of performance-based specifications.

Example 5

Relocation of school buildings as demographics change

It is common for manufacturers of modular buildings to have an inventory of hireable modules that can be used for applications where demand can change over time. This is often the case for classrooms. Refurbishment and reconfiguration are usually feasible for different requirements.

Case study 3

Project Stack

A residential, high-rise volumetric modular project designed by Sheppard Robson

Figure 5 Architect's impression

Overview

Project Stack is a modular housing concept exploring an effective solution for a high-rise residential building of up to 45 storeys. Apartments are constructed in 3m-wide by 9m-long modules, connected on site. This concept aims to maximise the inherent strength of a modular unit to allow it to cantilever and create a distinctive silhouette for a tall building.

The building is set out to a 3m grid. The tower floorplate is 9x9 bays. The core is a square of 3x3 bays and provides structural stability. The plan consists of four one-bedroom and four two-bedroom flats, with the latter located at the corners. The typical floorplan repeats, however, the balcony position has three variants. This creates a dynamic, spiralling appearance to the façade, and gives the balconies privacy and protection from the elements. The variant floor contains larger three-bedroom flats with double-width balconies.

As the whole building is set out to a three-metre grid, the façade can also be prefabricated and/or unitised. The modules are delivered as weathertight units. On site the joints are fire-stopped, and a rain-screen framework provided to protect the joints and support the material façade expression. A range of materials for the façade were explored from lightweight metal cladding to masonry cladding.

Case study 3 (contd)

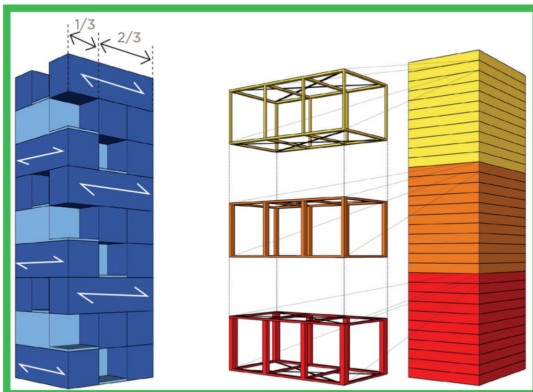


Figure 6 Volumetric modularisation

The chassis fits on a flat-bed lorry with a wide load, so it can be easily transported to site. There is a high degree of repetition within the flat types and modules, which is ideal for mass production. The modules containing bathrooms and kitchens would be volumetric, but the modules for bedrooms and living rooms could also be built as flat pack.

The principle of a 3x1 module allows a cantilever to be easily achieved, as two-thirds of the weight counterbalances the third that is unsupported. For tall buildings the chassis structure would vary every 10 storeys, so for a 30-storey tower there would be three chassis structures.

Lessons learnt

The tower layout is based upon a standards-compliant residential layout with a unit mix to meet the typical market demand. This arrangement is typically more challenging than a highly unitised hotel or student accommodation, the challenges included the fabrication of a single home from multiple modules, hiding of movement joints, connecting of services and transporting/installation of modules with only three walls. There can be a loss of net efficiency on the typical floor level due to increase in module-to-module wall widths and when building at height there will need to be more module types with differing strength capacity respective to their height on the building.

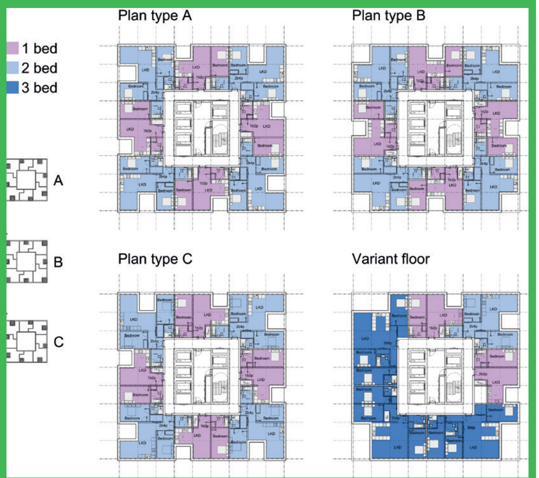


Figure 7 Modularity of floors

Case study 4

The benefits of developing standard products and platforms to manage them

National Highways' standard gantry concept

In March 2023, National Highways and the Royal Society of British Architects (RIBA) announced the winners of a design competition for a family of gantry products to help keep drivers informed and control traffic flows in the future.

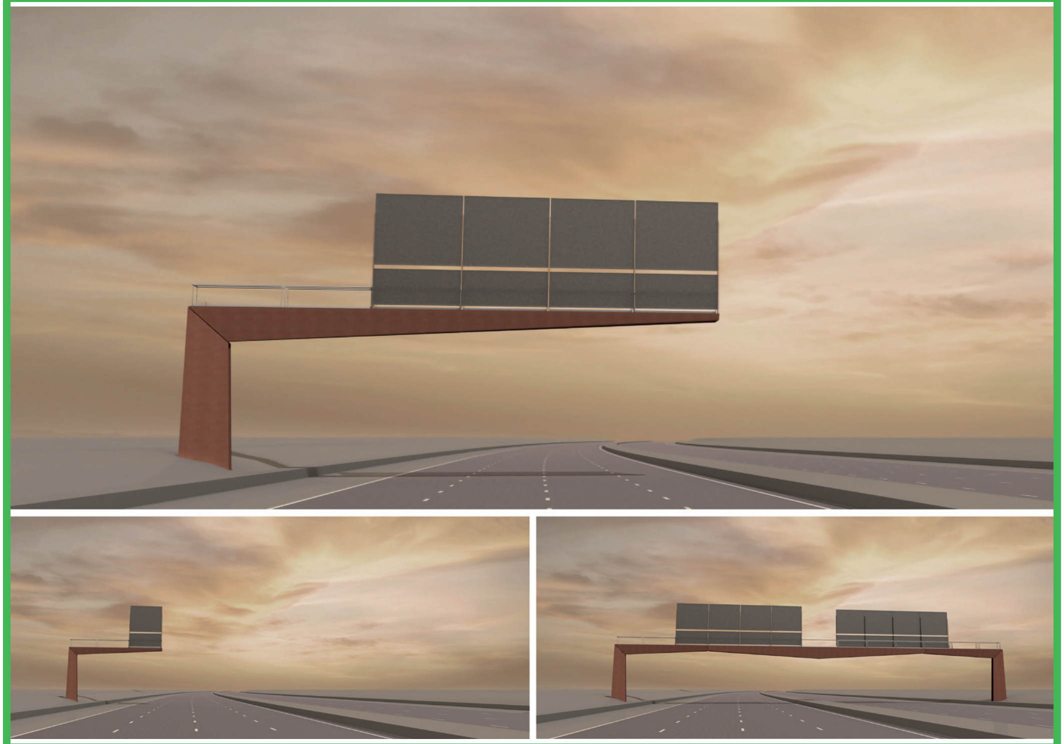


Figure 8 Architect's impressions

"The winning entry, created by Useful Studio (Figure 8), was chosen by the judges for its elegance and simplicity, and how cohesive the design concept was across a range of different structures. As well as a modern look, it will have less impact on the environment, with a projected reduced carbon footprint compared to current gantries" (National Highways).

This pre-production gantry concept's supply chain will now be developed, in order to provide a family of standardised products for roll out in new highway and improvement projects in two years from now.

These products will be held in the National Highways library of standard products with all related information subject to configuration management to ensure that precise configuration details will be available for future projects and maintenance requirements.

Case study 4 (contd)

This is the development of an offsite product family for which designers and manufacturers will be able to maintain digital twins for their respective purposes. This may be combined with the development of BIM catalogue services, where the design model and attributes are made available directly to the CAD application. The client will benefit from information provided to build their digital twins, which can be exploited throughout an asset's life.

Major infrastructure client operators have previously developed such catalogues of standard products but have found it challenging to manage the information effectively across multiple projects and different procurement methods. Effective deployment requires a stable strategy and consistent commercial policies that can drive continuous improvement and cost reduction, as required of any successful product.

The Environment Agency's SMART Object Library

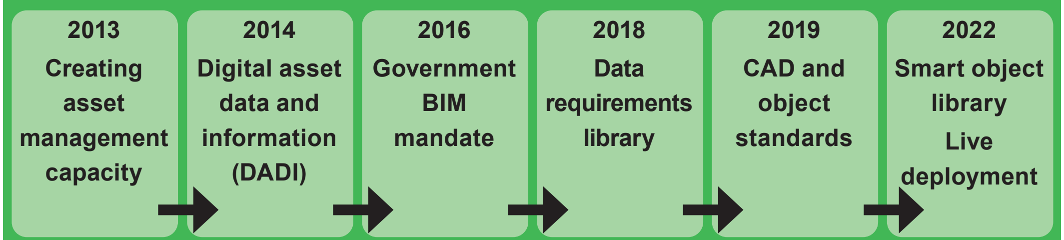


Figure 9 The Environment Agency's journey

The SMART Object Library is formed from asset details defined in the Data Requirements Library using the Environment Agency's CAD and Object Standards. It is file type agnostic, accommodating both proprietary file types and the open, IFC standard. It is hosted on Bentley Systems' Project Wise Components Center platform and is available to all those responsible for designing flood risk assets. During the Environment Agency's initial three-month pilot, 27 of a potential 110 users, generated an object reuse value that corresponded to a 3x return on investment (ROI) and this is projected to rise to a 25x ROI with 80% adoption.[98]

While there is a need to move towards open systems standards to maximise the opportunity to exploit standard products the current situation (in 2023) is that most major clients and their design consultants are developing their asset data management systems and standard component libraries in proprietary platforms. In other sectors, this has been a typical precursor to the emergence of open standards for electronic data interchange. An example of this is the ODETTE organisation which addresses the operational needs of the European automotive sector, having started with paperless commerce, such as despatch information and invoicing/ self-billing. The members of buildingSMART International are leading the initiative to develop open BIM standards in the construction sector.

Case study 5

HS2 Thame Valley Viaduct

Figure 10 Thame Valley Viaduct, artist's impression in 10 years' time (courtesy HS2 Ltd)

The High Speed 2 project needed to deploy efficient methods of construction across the first phase of its route from London to Birmingham.

The bridges and viaducts represent a large part of the project.

In 2018, HS2 collaborated with Buildoffsite to publish *Bridges and Viaducts DfMA Guide*. An early decision was taken to benefit from offsite solutions, and architects, engineers and contractors have responded to this brief. A great example is the Thame Valley Viaduct located in Buckinghamshire

The 880m-long Thame Valley Viaduct is being entirely pre-fabricated before being assembled on site. A collaboration between Eiffage, Kier, Ferrovial Construction and Bam Nuttall (EKFB), its design partner, a collaboration between Arcadis, Setec and Cowi (ASC), and specialist architects Moxon are delivering this elegant structure. Together they are using larger 25m beams which connect to each other to eliminate the need for an in-situ concrete diaphragm. They are also using precast pieces for the piers and the deck.

The benefits delivered by using large offsite components include:

- reduced carbon footprint by an estimated 33% (-19,000 tonnes compared to a previous design)
- improved durability and reliability
- time savings
- cost reduction

Case study 5 (contd)

- improved safety by reducing the need for people to work at height
- less deliveries to site, less HGVs on the roads
- less disruption to neighbouring communities
- high-quality finish of the precast concrete elements.

Figure 11 Completed piers for the Thame Valley Viaduct at the Pacadar UK factory (courtesy HS2 Ltd)

This is being achieved by applying lessons from similar projects in Spain. Two 'wide-box girder' beams are used per span rather than eight smaller beams, which simplifies and speeds up assembly.

Close involvement of the architect from the outset has ensured an elegant design that sits low into its landscape.

Definitions and scope of MMC

3

Nick Hacking, Sheppard Robson, J-P Cartz, WSP, and Andrew Rolf, Arup

Introduction

To be ‘modern’, MMC needs to be more than simply offsite construction. It needs to consider the wider processes and methodology that support offsite during design, construction, fabrication and installation.

However, MMC still applies to an exceptionally broad range of offsite construction techniques leading to generalisation and confusion within the industry.

To help establish a common understanding, the UK Government’s Department for Levelling Up, Housing and Communities (DLUHC) – formerly the Ministry of Housing, Communities and Local Government (MHCLG) – Joint Industry Working Group on MMC set out seven categories that are referred to throughout this guide, and detailed in this chapter, while considering how they are also applicable to the wider construction sector, including infrastructure.

However, the seven categories are limiting without the definition of an eighth category that considers the precondition and backbone to good MMC, offsite and DfMA.

Precondition: design, standardisation and digitisation (which has been referred to as category ‘0’)

This process is used to define the non-physical forms of MMC that are the backbone to success in the use of offsite construction techniques. The term includes aspects of process development, design and specification to enable the deployment of MMC construction in both building and infrastructure typologies.

It includes the brief refining stage, tying the client drivers or success factors to a benefits-based framework for MMC. Using the Buildoffsite/CIRIA Methodology for quantifying the benefits of offsite construction[(8)] or the CIH Value Toolkit[(4)] it is possible to link the client drivers to the metrics in which MMC typologies may be judged. For example, if timing is a strong over-arching requirement, such as within the Covid-19 pandemic response, forms of MMC that would enable programme reduction or predictability may be preferred – realising the clients benefit/value.

Strategic, often pre-project, standardisation plays a significant role during the precondition stage and is critical to the successful deployment of MMC products. Standardisation can cut across all forms of MMC, structural and non-structural, and can be determined as physical (component) requirements or non-physical process requirements.

Non-physical process may include the creation of standard design or procurement processes. Common design processes, such as using the same Building Information Modeling (BIM) systems can have significant impact when considering programmatic or multi-asset portfolio, rather than project, level MMC. For example, the NHS P22 (now P23)[80] procurement framework successfully developed a series of standard templates for BIM execution within healthcare projects, as well as template procurement support advice and execution. This level of standardisation across a sector should enable a reduction in repeat working, reducing costs and enabling shared learning and continuous improvement. Similarly, a cross-platform (BIM/GIS/Map) data management standard at an airport enabled the creation of an integrated visualisation system for users.

Where physical standardisation is considered, this sets boundaries and interfaces for structural, architectural or building services elements. Within the structural framework, it may inform the shell and core principles such as grid, floor-to-floor heights or structural zones. At a project level, standardisation of structural geometry should enable repeating structural components to be adopted. These may be permanent or temporary components; linking across Categories 1, 2, 3, 6 and 7. For example, the adoption of standard column sizes may maximise the potential for offsite construction, whereas the adoption of standard column grid may enable repeating formwork or fabricated floor elements to be used extensively. Where offsite products are non-standardised; it becomes increasingly difficult to enable these on small to medium-scale projects as it may become harder to manufacturer economically in small quantities. Programmatic standardisation of structural components provides significant opportunity for achieving wider MMC benefits than when employed on single projects – buying in bulk.

The standardisation of architectural elements, such as room geometry, façade geometry or fitting requirements can equally unlock significant benefits both at project and programmatic level. Standard room geometries can be linked holistically to both the structural and services requirements within a building form. At project level, the use of repeating forms should enable a simplification of design, ie achieving stakeholder sign off on one room form rather than multiple, and continual improvement within execution – repeating construction techniques across multiple instances.

Successful examples of room level standardisation exist within both healthcare, education and other forms of national social infrastructure. Within healthcare, the P22 repeatable rooms have provided a framework of standard room geometries with embedded standard components. This approach has streamlined the design and stakeholder engagement of these space types.

Within building services design, the use of standardised components is heavily linked to the successful deployment of the architectural design. The successful development of MMC products, Categories 5 and 6, relies on repeating geometry and performance requirements.

The use of unified specifications across these approaches is important to underpin the geometrical requirements. Having performance requirements at project or programmatic scale will enable MMC. For example, developing generic requirements for door-sets, ceilings and finishes within classrooms; geometrical, interfaces and

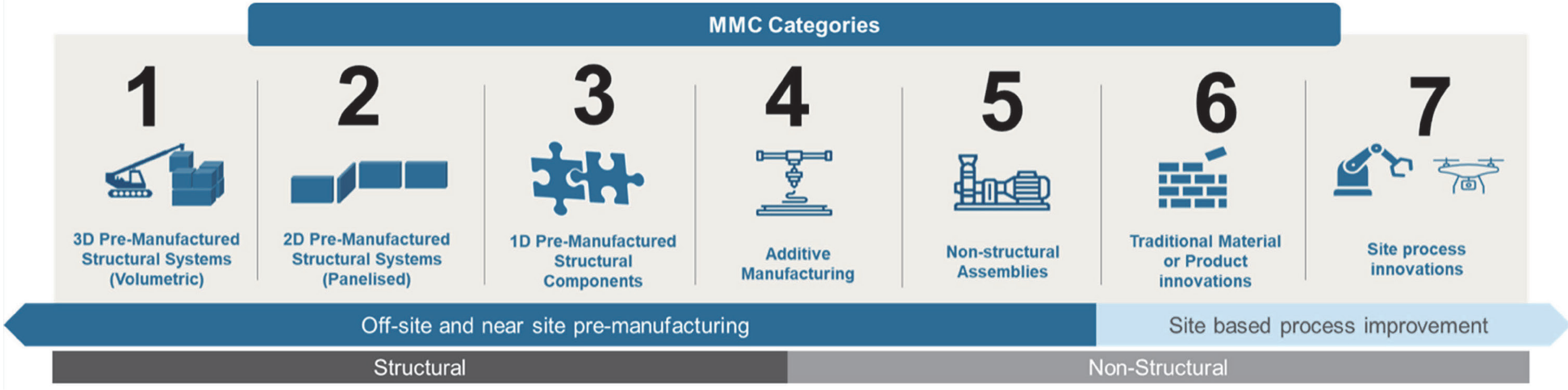


Figure 12 MMC categories (courtesy TfL)

performance requirements, enable manufacturers to develop and innovate around a single specification. Such standardised products may equally be very large structures such as aircraft stand nodes, water treatment modules, or even major parts of bridges and viaducts.

This preconditioning activity is underpinned by digital processes through design, and into delivery. Successful delivery of well managed BIM Level 2+ can be used to support the deployment of the standard products developed. Adopting fully parametric standard components to create kit-of-part libraries that may be used to develop building forms, but also generate specification, risk, cost and carbon data.

Such preconditioning, or ‘Category 0’, focuses on developing the framework for offsite construction to ensure that projects achieve the over-arching benefits of MMC – better, faster and greener.

Large serial clients, particularly in the transport, utilities, flood protection and social infrastructure sectors are well placed to exploit such strategies, and many are doing so.

Category 1 – 3D primary structural systems (modular or volumetric)

Category 1 includes modular volumetric units produced in factory conditions before onsite installation. The units can take a variety of forms, ranging from the basic structure to one with internal and external finishes and services already installed.

In buildings this category of MMC is most suited to short span cellular repetitive construction types such as hotels, student housing, temporary buildings, and residential buildings both houses and flats. The repetitive nature of the building generates the economies of scale, and the short spans allow whole modules to be transported by road. They will often be at the scale of a single room, but this category includes smaller scale modules such as bathroom pods. Category 1 systems can be either point-loaded or line-loaded.

Infrastructure projects also use volumetric modules for aspects such as plant rooms, corridor modules, enclosed link bridges, gantries, stair and lift towers/shafts, aircraft stand (loading) nodes.

Category 1 may be formed fully or partially offsite, with variants including:

- structural chassis only – not fitted out
- structural chassis with internal fit-out
- structural chassis, fitted out and including external cladding/complete roofing
- structural chassis and internal fit-out, including 'podded' room assemblies, such as bathrooms, kitchens, water dosing kiosks, complex plant rooms etc.

Knowing the system variants and specifications is important when considering Category 1 forms. These may shape the design approaches.

The variants can be used in the following three configurations:

- whole building systemised
- hybrid construction – part-systemised, part-traditional (eg traditional core/ground-floor podium)
- hybrid construction – secondary structure to enhance system performance (ie build at height).

This volumetric modular approach imposes some level of rigour within the chassis which, to be successful, is reflected within the spatial design. The adoption of Category 1 volumetric construction should be considered from the outset of a project; allowing the building form, grid, chassis to be developed around the volumetric module.

Logistics, both on and off site, need to be carefully assessed when considering Category 1 forms. The offsite routes need to be reviewed to determine potential impacts on module sizes, ie it is no good designing for modules that cannot be safely or efficiently transported to site.

Category 2: 2D primary structural systems (prefabricated structural systems such as CLT, pre-cast concrete, lightweight frame and load-bearing panel systems)

Category 2 includes flat panels systems produced in factory conditions and installed on site. It applies to major structural elements as well as floor, wall and roof systems.

Historically this category has mainly been associated with panelised systems in the residential sector, by implication, it includes other systemised 2D structural components (as Category 3 covers non-systemised primary structure).(13)

These systems are ideally suited to repetitive building and infrastructure types with longer spans such as offices, schools, larger plant rooms, flood defences, bridges etc. They include, modular façades and modular internal wall systems, roof and floor cassettes, and a range of systemised precast concrete products. This category includes both superstructure and systemised sub-structure elements, such as prefabricated ring beams, pile caps, driven piles and screw piles, some bridge beams and retaining wall sections.

As design for assembly becomes more mature, variants increasingly include the integration of other categories' components such as insulation, linings, ducts, pre-positioned fixings, external cladding, roofing, doors, windows, drainage, electrical and plumbing elements, Internet of Things (IoT) Connected Places Catapult[54] elements (eg energy performance sensors, load and corrosion/condition sensing and management components etc), forming multi-functional structural cassettes. Examples of Category 2 systems include:

- **A range of timber, light-gauge steelwork and precast concrete prefabricated** elements used as 2D-elements for form load-bearing wall and floor systems; non-loadbearing or architectural elements being included with Category 5.
- **Offsite formed timber** products would historically have been limited to pre-assembled stud or joist systems, connected using a range of timber sheet materials.
- **Larger format timber sections formed in cross-laminated-timber (CLT)** is becoming increasing popular. This now being used to form wall and floor elements which would traditionally have been formed using prefabricated studs or joists.
- **Light-gauge steelwork** products are similar to traditional timber 2D elements, using a series of cold-rolled steel joists or studs. These are pre-assembled, but do not necessarily require the sheathing of the timber equivalents.
- Both **timber systems and light-gauge steel systems** can be available in pre-insulated and/or pre-serviced modules. These structurally insulated panels (SIPS) can be used to form load-bearing external and internal wall systems.
- **Precast concrete panel elements** may form wall or floor elements. Wall elements in precast concrete may be solid or twin-wall, where twin-wall systems adopt two-leaves of thinner precast panels connected via reinforcement trusses,
- **Floor elements** in precast concrete may be solid, hollow-core or lattice-slabs (omnia or truss deck forms).
- **Wall elements** can be used in combination with Category 1 and Category 3 systems, forming circulation cores or stability elements.

Similar to Category 1 elements, the size of components can be controlled by site logistics both on and offsite.

Category 3 – Pre-manufacturing components (non-systemised primary structure)

Category 3 is focused on smaller components than those of Categories 1 and 2. This reduces, but not eliminates, some of the logistics constraints that can be encountered with larger components. It is extensively used in both the infrastructure and building sectors.

Key examples of Category 3 include:

- **Steel frame construction** – using standard off-the-shelf hot and cold rolled steelwork elements forming beams and columns. Elements are typically connected via welded or bolted connections. This can be combined with 2D panelised construction forms; precast or CLT slabs or walls.
- **Precast construction** – using either project specific or standardised precast concrete elements to form beams and column elements. Elements are typically connected using cast-in bolt connectors or onsite grouting. Precast elements can be combined with 2D panelised construction forms; precast or CLT slabs or walls.
- **Timber frame construction** – using standardised glulam, CLT, laminated veneer lumber (LVL) or similar engineering or natural timber construction products to form beams and columns. Elements are typically connected using bolts, screws, nails or glues or, in large structures, more in-situ concrete.
- **Modular forms of foundation construction** – such as precast ground beams, screw piles etc to reduce the amount of works on site when forming foundations.

Category 3 MMC is typically highly 'configurable' to suit project requirements. Using smaller componentised MMC allows non-identical building forms to be created and makes it easier to use Category 3 forms of MMC within complex building forms, such as extensions to or refurbishment of existing buildings. It can also provide low-cost components adapted to the OSM of Category 1 and 2 systems.

As with all MMC forms, what makes Category 3 construction 'modern' is the design approach taken to maximise the potential for offsite construction. Using standard, rationalised, components that can be repeated in multiple instances across a structural scheme gives greater potential for offsite. For example, ensuring consistent grid structures that enable the same column, beam and floor elements to be used minimises the number of components and maximises the potential for OSM. Using a 'configurator' approach allows variations within macro form while achieving standardisation at component or manufacturing process level.

This is really important when considering offsite construction forms using Category 3 technologies. Simply designing and applying MMC will not lead to good results and may not engage the supply chain. For example, if a building frame is designed with a high percentage of bespoke element geometries, it is unlikely to be attractive to the manufacturing industry and challenges procurement.

Category 3 needs to embed a DfMA approach from the start to maximise the potential and reduce waste. This requires an understanding of manufacturers' capabilities and their cost drivers. This is most easily achieved by engaging suppliers early to determine the best forms or approaches to be manufactured, informing the design solutions. Over time, designers will gain their own understanding of what the available capabilities are and how their decisions are likely to affect costs. In some sectors, suppliers publish design guides (eg for different types of bridge beams) which ensures that designs are compatible with the form work, moulds and jigs available.

A key benefit when adopting Category 3 construction is the potential for circularity in the whole life cycle of the project. The use of repeating components with defined parameters and reversible connections should allow buildings to be designed for disassembly or deconstruction as well as assembly. Provided the approaches are realised within the construction of the building, eg ensuring there are bolted, mechanical fixings between precast components, would provide greater scope for repurposing.

Digital design data is an important part of defining components within Category 3; embedded parametric data into the component libraries to improve the quality of the design and construction processes, eg providing precast elements with embedded data on load capacity, material specification, and compliance and quality assurance data. Maintaining this data again allows greater potential for circularity at the end or repurposing of an asset.

Embodied carbon of all construction products needs to be carefully considered, particularly within the structural systems. Reviewing the embodied carbon from production to construction (A1-A5) of Category 3 products is key, particularly if processes adopt high-carbon materials to accelerate manufacture. There is a greater need for individual Environmental Performance Declarations of such products.

Note

BS EN 15978[(23)] and the RICS[(26)] set out four stages in the life of a typical project, described as life-cycle modules:

- Module A1–A5 (product sourcing and construction stage).
- Module B1–B7 (use stage).

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

Extrusion methods for forming concrete continue to evolve. Additive manufacturing is becoming used in the form of 3D printed concrete (including alternative, low carbon AACM concretes). This has the advantage of creating forms that are otherwise impractical. In the offsite sector, this is more likely to be exploited in the DfA process, ie there is a tendency to reduce the number of components, while potentially making their form more complex.

The 3D printing of structures tends to be site based due to the scale, lifting and transport challenges.

Additive manufacture can use metallic materials and is not limited to materials that can be extruded or printed. Components for maintenance and repair are now being created where they are needed, eg when suppliers and clients are remote from each other. There are reports of this being used to create components to repair ships at sea and other military applications. One could envisage this applying to the facilities management sector in the future.

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

Category 5 is a wide encompassing term which covers the architectural, civil engineering and building/engineering services components that may be manufactured offsite.

Although only noted within one category, the architectural and building/engineering services components can form a significant proportion of the capital costs of a project, particularly in social infrastructure such as school and healthcare buildings. Typically, these combined elements will form the greater proportion of the project costs when compared with the structural framing (Categories 1 to 3), however it is important to note that the structural framing will form a significant enabler to effective deployment of Category 5 MMC. It is important that these elements are considered holistically alongside the structural framing categories.

Engineering services assemblies are commonly used in infrastructure projects. A wide range of standardised solutions have been developed across sectors such as airports, rail, road, and public utilities. Examples include pump units, power/heating plant modules, signalling, lifts/lift shafts, heat exchangers, IT infrastructure, and structural healthcare packages etc.

While most civil engineering projects are dominated by large structural elements, linear Category 5 elements may also be exploited. Engineering services can be significant and are discussed as follows. Linear infrastructure, such as roads and railways, adopt platforms, ducting, sound absorbing and other barrier products along and across their routes, which may be pre-manufactured. Numerous utilities and networks require large tanks, often with significant chemical resistance and assured performance over extended life cycles. These too may be precast, with innovative materials and protective technology integrated into them in the factory.

Architectural components

Architectural components can be divided into external and internal components that form the building façades and fit-out.

Offsite approaches to façade construction can vary from full or partial; with varying benefits and considerations required for each form.

Full offsite construction of façade components comprises of elements which include not only the internal framing, but also the external finishes and apertures, including windows and doors etc. Large, prefabricated panels can be load bearing, as part of the overall structural framing, or non-load bearing.

Load-bearing panels, typically precast concrete, form sandwich panels comprising a load-bearing element tied to the structural frame, insulation and then the external cladding finish. These forms of panels are typically a single storey high in order to tie to the structural framing. This form of construction has significant time benefits as the building is made weather-tight quicker.

Non-load bearing panels can be made in a range of materials and can be installed over greater heights, typically, two-storey elements. Again, systems can be fully finished offsite to enable reduced programme and improve quality of installation.

In larger infrastructure buildings, such as airport terminals, glazed façade modules may span multiple storeys. While they may not be supporting the floors and roof, they will still need to resist significant loads and may have characteristics shared with Category 2.

With fully formed construction, the temporary condition becomes critical. Understanding the material required to ensure that all elements can be lifted without adverse displacements that could affect the glazing or gaskets needs careful consideration.

Partial offsite construction of façade components reduces the number of components that arrive onsite but retains the separation between layers of the façade. Examples of partial construction include non-load bearing insulated panels where the inner leaf of a façade arrives preassembled with studwork, insulation, and external and internal boarding already installed. Such systems allow faster weather-tightness while retaining some flexibility of façade forms.

Internal fit-out elements typically comprise walls, staircases, raised floors, screens and apertures. Offsite solutions for internal fit-out may include pre-assembled, pre-finished and pre-serviced partitions or preassembled doors and screens.

Within buildings, fixtures and fittings are also included within most offsite appraisal calculations (PMV). The methodology for offsite construction of fixtures should be considered within the design stage, particularly if there are significant requirements within the building form.

Building/engineering services components

Building/engineering services components can be classified as primary plant, distribution and terminal when considering MMC or offsite construction approaches.

Primary plant components comprise the elements traditionally housed within plant rooms or energy centres. They may include prefabricated air-handling units, modular generator or battery systems, or pumping or valve sets.

The installation of OSM primary plant distribution can significantly improve not only the programme, but also the quality of installation. Services can extend beyond individual elements of equipment to include plant room distribution sections of pipework, ductwork, cabling etc to reduce the site works to the interfaces between primary plant and follow-on distribution. This enables services to be tested and commissioned in factory settings ahead of installation on site.

Ideally, offsite primary plant distribution also includes the structural and architectural components, reducing the need for additional secondary support that would increase capital and carbon cost. The creation of larger modular plant decks or towers with integrated structure, services and façades provides significant advantages.

Similar to the façade modules, the logistics of installation need to be considered early to ensure that the ambition to deliver and install/assemble plantrooms on site is achievable in practice. The maximum deliverable and liftable module may dictate the size of components.

Distribution services components may comprise of both vertical and horizontal services modules.

Vertical distribution modules are typically located in risers within the primary building frame and support a range of vertical services – both mechanical and electrical. Vertical services module frames are often self-supporting within a secondary framing to enable factory construction, delivery, lifting and installation.

Horizontal services modules distribute services from vertical risers to rooms and within open plan spaces. Similar to the vertical modules, horizontal service modules are typically formed using secondary steelwork rafts or full container frames.

Both vertical and horizontal services modules can be integrated with finishes to reduce the extent of follow-on trades. Both can undergo pre-delivery, factory-condition commissioning and testing to reduce the works on site and improve quality of installation.

Similar to the plantroom spaces, distribution modules need to be considered early within the design so that logistics can be tested to assess the limiting module sizes and viability. In some instances, depending on the scale of installation, the secondary framing may need to be considered within the spatial allocation to ensure secondary framing is allowed for.

Terminal services components may comprise elements such as integrated plumbing systems and bed-head services (in healthcare or hotel settings). These terminal services are often integrated within the final finishes and fixtures, significantly reducing the need for follow-on trades within the installation.

Modular wiring components and wiring looms may be employed to minimise connections and accelerate installation.

With all services modules and plant spaces, it is important to assess whether secondary framing for installation is leading to increased embodied carbon of the services installation. This should be considered when optioneering the potential extent of offsite services construction. DfA encourages the integration of functionality into a reduced number of components.

Category 6 – Traditional building product led site labour reduction/productivity improvements

This category is out of scope of this guide.

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

Category 7 MMC considers the digital interventions and construction innovations that will enable a safer, better quality construction process. This includes physical and non-physical interventions that may be employed to realise MMC benefits.

Physical interventions are focused on improving the safety and delivery of construction projects. This may include elements of robotics or modular temporary works and formwork.

Robotics are used in several areas, particularly for transportation or within high-risk works. Remote controlled compaction, craneage and excavators can be used to reduce the need for operatives to work in certain areas.

Wearables and drones can be used to monitor productivity and progress, but also alert to biometric changes or nearby hazards. Smart glasses or helmets can be used to support augmented reality, activity and communication monitoring, enabling more effective methods of working. Smart sensors can be used to communicate and record operative or equipment location and alert to hazards.

Modular formwork systems can be adopted to reduce the turn-around of construction activities, particularly when constructing hybrid structures.

Non-physical interventions centre around process and monitoring. Using 3D scanning, augmented reality, 3D reinforcement detailing, or fabrication can assist in the co-ordination of construction activities. This can be built around a comprehensive Common Data Environment (CDE) and BIM system that will effectively manage data and be used to aid planning, estimating, programming and also carbon management. Many of these aspects are equally applicable to offsite activities.

The assurance of offsite work is covered in more detail in **Chapter 10**.

MMC are systemised so they are likely to be candidates for applying efficient rules-based-design processes. Some suppliers provide potential customers or their designers proprietary design guides for use within a project to ensure that a system is used efficiently.

Whole life cost

4

Nigel Fraser, Buildoffsite, with contributions from Candice Lemaitre, TfLP, Dr Matthew Badger, EA, Ali Mafi, Timist, and Bernard Williams, IFPI

In the following paragraphs it is important to differentiate between 'cost' and 'price'. In general, price may be related to cost, but this is not always the case and the price to the client will be managed in different ways depending upon market conditions, the procurement process and the type of standard contract used (JCT, NEC4 etc). What is evident is that reducing costs and risk is ultimately required for lower prices to be sustained.

The PMV metric is increasingly being used to evaluate the maturity of MMC use in projects and tender proposals.

However, PMV looks at costs rather than outcomes, and does not necessarily adapt well to accessing the maturity of MMC. It is therefore limited and unlikely to fully consider environmental or wider social benefits.

The British Standards Institute (BSI) has been working upon standards for life cycle costing for some time, and while the construction sector has been increasing its focus on the standards, it is challenging.

The budget holders for capital projects are often different to those responsible for operating assets, even within organisations that are both owner and operator of a facility and each may have objectives which optimise their own requirements. However, the climate crisis and, in particular, the need to use energy efficiently has brought the two sides of many organisations closer together. There remains a need to broaden the focus beyond energy use in many cases.

"PMV provides a metric in % value in relation to the quantity of pre-manufactured solutions on any given asset, which includes all materials supplied to site. It's a proxy measure used by government to transform the sector into an advanced production state (most factory manufacturing) and increase performance of capital projects.

PMV services are used through the feasibility, design, construction and final account stages. PMV estimation is carried out at strategic stage, in line with setting the desired programme or project outcomes. For example, a higher PMV will likely lead to a faster and more certain capital programme. The estimation sets the principles of design and construction methodology, assisting the supply chain to plan for certainty, and aggregate contractor and supply chain work packages. Estimation is carried out by predicting the materials cost, proportioned over the gross construction cost (including preliminaries). Setting a PMV for the typology, delivery model and tenure is critical to achieving desired portfolio cost, speed, safety, carbon and programme outcomes".

$$\text{PMV \%} \ \frac{\text{Pre-manufactured value (£)}}{\text{Gross construction cost}} \times 100$$

UK Government target = 55%

Best practice = 55/60%

Industry leader 60/70%

From Candice Lemaitre, TfLP (personal communication)

A key development has been the issue of the Construction Playbook,[1] which requires *"Having a clear understanding of the whole life costs and risks of delivering a project or programme is best achieved by producing a should cost model."*

Standards and guidance documents are becoming increasingly available with more comprehensive guidance for the construction sector; there are three major BSI published standards PD 15686-5:2008[14] BS 8544:2013[15] and BS ISO 15686-5:2017[16] with this focus.

The RICS has issued further guidance on this subject, Lifecycle costing,[17] and has updated its new rules of measurement (NRM),[18] publications including:

- **NRM 1:** Order of cost estimating and cost planning for capital building works.
- **NRM 3:** Order of cost estimating and cost planning for building maintenance works.

"Some types of Environment Agency project are not suited to the use of the PMV metric. Reservoir or embankment construction, beach renourishment projects, and natural flood management schemes are likely to involve very low levels of pre-manufactured construction components. However, their delivery can be made more efficient through the use of Category 7 onsite MMC techniques, such as the use of GPS controlled plant, robotics, drones, artificial intelligence, and remote sensing. Therefore, these projects could be highly MMC mature, despite low levels of PMV."

Dr Matthew Badger, Environment Agency (personal communication)

Capital cost

Offsite has potential to significantly reduce capital costs, however that is dependent upon some pre-requisites:

- efficiently run factories with multiple clients and consistently high use rates
- healthy competition
- financially robust clients and suppliers
- use of lean manufacturing methods (and not construction in a shed)
- rigorous co-ordination of interfaces with onsite works (foundations, services, access routes, information flows etc).

There is potential to reduce capital cost in this environment, through:

- lower labour costs and related expenses
- higher productivity
- less susceptibility to site-related risks, such as adverse weather conditions
- less waste
- fewer deliveries with higher value loads
- less snagging on site.

However, market price and competition are crucial, and this means designing a project to ensure healthy competition – particularly among potential offsite suppliers. This requires assuming an offsite approach from an early, pre-tendering stage; the project's procurement strategy needs to embrace this.

In the design context, greater detail will be developed at an earlier stage and, in the case of a product, system or platform, a large proportion of this effort will be used repeatedly across a potentially large number of projects that will mainly require configuration of the product, system or platform, within pre-agreed rules. Note that it is advantageous to develop, test and certify such products, systems and platforms, including their assembly processes, before the projects and programmes need them.

In a design studio it makes sense to manage design outputs in digital formats so that they may be used repeatedly, and rules-based configuration tools applied to them. This will increase design productivity and will result in more detail to enable savings in later stages. Creating such detail without reusing standard design elements for a traditional build or bespoke offsite solutions may lead to increased design fees in the near term. Machine readable regulatory requirements (eg Building Regulations, highway design and construction requirements) are being rapidly developed and these, alongside digital compliance checking tools that are being developed, will assist design studios ensuring that repeated use of standard design outputs in digital format are still compliant with the relevant regulatory requirements.

Labour costs are primarily a function of productivity and labour rates. Labour productivity on construction sites is significantly lower than for work organised in factories.

For illustration, 1000 hours on site with a productivity rate of 50% (500 productive hours) at a cost of £50 per hour = £50,000.

The same output from a factory with 90% productivity and labour at £25 per hour (including direct overheads) would need 556 hours at a cost of £13,900.

This difference can be significantly amplified when the construction site is in a secure area, with inspections required of materials and personnel.

For example, if the productivity rate is reduced to 25% due to factors associated with working on a highly secured site involving both materials and personnel checks plus potentially long transfer times to the actual place of work and inefficient, unpredictable logistics due to ongoing campus operations etc, the cost could increase to £100,000.

It is not surprising that sites such as airport and prison operators have been consistent users of offsite processes.

Factory overheads are comparatively low when there is a consistent flow of orders from multiple clients and projects to maintain high use rates for factories. This can be difficult to achieve in the construction sector but adopting standardised, accredited, construction systems and 'platforms' can help this.

These numbers may not represent a particular context, but the order of magnitude is the main point. The key challenge is how to enable such a cost reduction and ensure that it is not lost through issues arising down the line, for example, when offsite assemblies are installed on site.

A holistic approach to cost analysis needs to be adopted, starting with an understanding of the design intent and the standardised processes for assembling systems. Only by considering the whole end-to-end process can an assessment of the overall cost be determined. Minimising costs for every element can be counter-productive, and this is demonstrated well in *Seeing the whole value stream* by Jones and Womack (2002)[19].

A study by a Buildoffsite member demonstrated that their projects delivered using a volumetric modular system resulted in more certainty regarding project completion and out-turn cost than traditional construction methods. There may be several reasons for this. A shorter project duration may result in less opportunities for risks to materialise with associated compensation claims. Standardised assembly operations with specialist tools and jigs may result in both consistent performance with less snagging required. A key point is that when comparing tender submissions, it is important to evaluate the reliability of the out-turn duration and cost for alternative approaches and take these into account.

When considering this list, the perceived 'expense' of the cassette (in **Case study 6**) is likely to become insignificant compared to the value it could bring.

Such an approach does change how project work packages are defined and risks assessed and managed.

Many project costs directly relate to its duration and, consequently, faster delivery can help to avoid additional costs. These may range from site welfare facilities and scaffolding to other typical project overheads, including a range of management roles.

Some costs, such as long-term scaffold hire and inspection charges, may be avoidable by using specialist materials handling equipment on an 'as needed' basis. The lifting strategy and crane use can often be significant cost influences. Large crane availability can also be a consideration when using large, heavy modules and/or long crane booms.

Ali Mafi, Timist,[81] reports that time-related costs are highly significant.

- Time is related to 70%-80% of the project cost.
- The risk of cost overruns is often time related; the value of most claims is time related.

Case study 6

When is a floor cassette more than just a floor?

A floor cassette may act as a jig for setting out the structure, while providing ducting for a heating, ventilation, and air conditioning (HVAC) system and incorporation of a floor finish and connections for other fittings, both temporary and final product. While the floor cassette may seem expensive it could offer many opportunities that significantly reduce project duration and cost, such as:

- Assuring the alignment of a structural steel frame allowing the cladding work to start earlier.
- Synchronising assembly cycle times with other major modules (roof, cladding, frame etc) to establish a predictable and fast facility assembly process.
- Avoiding the need for a wet trade (for the screed) and associated drying time.
- Providing a ceiling for the space below.
- Enabling rapid installation of:
  - temporary edge protecting safety barriers
  - architectural metalwork (balustrades, air diffusors etc)
  - people movers
  - modular wiring looms.
- Bringing forward the times when other major elements can be installed.
- Enabling more work packages to progress in parallel without getting in the way of other work packages.
- Reducing risks to the project (for example weather related and 'right first time fit' challenges).

- When and how fast a project completes depends on the constraint/bottleneck of the project delivery system.
- Project constraints often move many times weekly.
- To reduce project time, the focus should be on improving the project constraint.
- The gain from a change to the project constraint (at a point in time) is two days in 98% of cases.
- A significant percentage of offsite works is required to have a significant impact on a project's duration.

This last point is supported by work done on scheduling construction projects that use complete offsite and 'platforms' systems where potential time reductions can be very significant.

Use of such system-based approaches and, indeed, modular solutions within a more traditional approach, does have a significant influence upon the planning of a project's suppliers payments schedule.

In-use costs

Offsite methods have the potential to reduce in use cost through:

- earlier availability and income generation
- more time for detailed design of products and systems for:
    - resilience (fabric first approach)
    - integration of remote sensing and control functions
    - maintenance – repairability is a key consideration, continuous improvements to standard solutions leads to lower cost designs; easier to maintain or replace parts
    - adaptability where needed
    - obsolescence management.

Together these can make a significant contribution to reducing whole life costs.

End of life costs

End of life, repurposing and recycling are all factors that can be considered for any design. However, the need for offsite products to be designed so as to be manufacturable and easy to assemble also provides opportunities to reduce end of life cost. This can occur through more detailed design for:

- resale for relocation, reconfiguration, or recycling
- incorporation of sensing technologies into structures to:
    - maximise their durability
    - log how they have been loaded so as to make them reusable
- deconstruction (often closely linked to the onsite and factory assembly processes, only in reverse).

Example 6

The evolution of the Seismic platform

This collaborative platform project *"developed a patented connector block that would be available as a component for any modular buildings supplier to purchase and use. To get the wider market to use it, it had to provide better value than their current system. The connect block facilitates a 50% reduction in steel and a 50% cut in assembly costs. Importantly, it enables the volumetric units to be manufactured in two-dimensional cassettes, IE. Floors, ceilings, roofs and walls."*[20]

This provided a basis for developing the Seismic II platform. It *"showed how a standardised light steel frame could change the way new schools were designed and constructed".*

"Seismic II looked at the whole life performance of the buildings" … "to reduce the construction costs and whole life costs of buildings by a third, while seeing those same buildings delivered in half the time and with a 50% reduction in carbon emissions from the sector."[21]

The Seismic platform aims to deliver a *"A 47% improvement in whole life value compared to traditional construction methods" … "a 70% reduction in whole life carbon emissions, through reduced waste, improved building heat and energy performance and the recyclability of the components."*[12]

Platform-based approaches are setting new benchmarks for construction, demonstrating significant reductions in both capital and operating costs.

Further information on the Seismic II platform may be found here:
https://constructingexcellence.org.uk/seismic-ii-to-shake-up-mmc-with-our-members-blacc-tata-steel/

See **Case study 1 (Chapter 2)** which uses a tool to consider whole life aspects of a project. It has been used to help determine annual maintenance costs required for development schemes.

Whole life carbon

5

Contributions from Lilian Martins WSP, Nick Hacking, Sheppard Robson and Nigel Fraser, Buildoffsite

Whole life carbon emissions result from the manufacture of materials, construction and the use of a construction project – buildings and infrastructure – over its entire life, including its demolition and disposal.[22] A whole life carbon assessment provides a true picture of a building's carbon impact on the environment. BS EN 15978:2011[23] sets out the overall principles of embodied and whole life carbon measurement in the built environment. It also covers the assessment of the environmental performance of buildings, while the associated BS EN 15804:2012+A1:2013[24] covers the environmental performance of individual products.

It is estimated that 80% of a product's environmental impact is determined at the design stage of the project, this is closely tied in with the cost for carbon reduction throughout the project's life cycle. The benefits of a whole life carbon assessment are multifaceted including:

- Accounting for emissions, which cannot be cut without understanding business as usual protocols.
- Assessment promotes an understanding of resource efficiency and encourages the reuse of existing materials.
- Illustrating the carbon benefits of specifying end of life, increasing reuse, recycling and supporting the Circular Economy.
- Encouraging a 'fabric first' approach to building design thereby minimising mechanical plant and services in favour of natural ventilation.
- Considering operational and embodied emissions simultaneously to find the optimum solutions for the development over its lifetime.
- Identifying the impact of maintenance, repair and replacement over a building's lifetime, which improves resource efficiency and reduces life cycle costs, contributing to the future proofing of asset value.
- Encouraging local sourcing of materials and short supply chains, with resulting carbon, social and economic benefits for the local economy.
- Encouraging durable construction and flexible design, both of which contribute to greater longevity, reduced obsolescence of buildings and avoiding carbon emissions associated with demolition and new construction.

Whole life carbon emissions are the sum total of all asset-related greenhouse gas (GHG) emissions and removals, both operational and embodied over the life cycle of an asset including its disposal (modules: A1–A5 upfront, B1–B7 in use, C1–C4 end of life). Overall whole life carbon asset performance includes separately reporting the potential benefit from future energy recovery, reuse, and recycling (Module D) (LETI, 2020).[25]

LETI[25] and RIBA[82] have issued benchmark rates for whole life carbon emissions for buildings, which are now being used to benchmark projects.

Factory manufacturing of systems provide a means to a more carbon accountable supply chain with greater traceability of materials and processes.

Case study 7

The Forge, Landsec's MMC benchmark P-DfMA project

The Forge is Landsec's first Net Zero Carbon (NZC) office development and will be constructed and operated in line with the UK's Green Building Council's (UKGBC) framework definition of net zero carbon buildings.

It features two elegant buildings offering c139,000 square feet of best-in-class sustainable office space set around a bright public courtyard in the heart of Southwark.

Figure 13 The Forge (©Bryden Wood, courtesy Jocelyn Low)

Designed by architects Piercy & Co and Bryden Wood, The Forge has been built using an innovative platform approach to construction in which a standardised kit of parts had been used to create an efficient building system.

In addition to its NZC credentials The Forge has the following sustainability features:

- All electric building using heat pumps to provide heating, cooling, and hot water requirements
- Powered by 100% renewable electricity
- 5-star NABERS UK design stage rating
- Roof top PV, green roof areas and rainwater harvesting all contributing to an BREEAM Excellent rating
- 18.4% reduction in steel compared with traditional steel frame
- 13% less concrete compared with traditional benchmarks

Case study 7 (contd)

- 50% GGBS content in substructure concrete and 40% GGBS content in P-DfMA floor slabs
- c25% reduction in overall embodied carbon
- Any remaining embodied carbon offset using Gold Standard carbon credits.

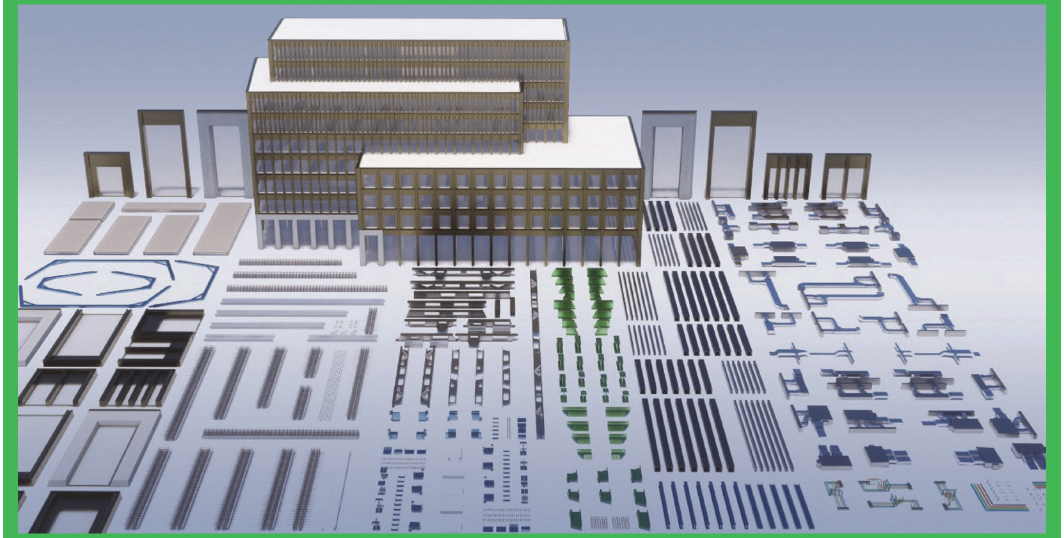


Figure 14 P-DfMA using a 'kit of parts' approach to construction (courtesy Bryden Wood)

The project used a construction management (CM) based approach to procurement, appointing Sir Robert McAlpine, and Mace in an innovative joint venture partnership to fill the newly created role of Manufacturing and Assembly Manager (MAM).

The following key specialist supply chain contractors were engaged at an early stage in the process to help develop the Platform Design for Manufacture and Assembly (P-DfMA) solution:

- NG Bailey – offsite manufacturing of M&E assemblies
- Hotchkiss – pre-manufactured ductwork
- Hall & Kay – sprinkler installations
- Easi Space – prototyping and temporary works fabrication
- Kone – lift services
- DAM Structures – steelwork fabrication
- Aluprof – unitised cladding

In modern methods of construction (MMC terms), it deployed Category 1, 2, 5, 6 and 7 component solutions:

- Category 1:
  - Strongbox structural core elements complete with prefabricated steel stairs
- Category 2:
  - Precast concrete 'twinwall' flat panels used to construct the lift core

Case study 7 (contd)

- Category 5:
  - Floor cassettes; fan coil modules; pipework modules; distribution and lighting modules
  - Vertical risers: pipework; electrical; sprinklers; ductwork
  - Infrastructure: roof plant room multi-service distribution modules; heat interface unit assemblies; packaged pump rooms; packaged low voltage switchrooms; plant equipment skids.
  - Unitised cladding
- Category 6:
  - Pre-sized and cut to measure materials
  - Modular wiring
- Category 7:
  - Pre-manufactured beams
  - Platform temporary works system (including re-useable shutters, props, faux columns, and safety handrail system)
  - Steelwork prefabricated as components.

The project has been designed and constructed to deliver the world's first major commercial development using a platform approach to design for manufacture and assembly (P-DfMA). The aim was to demonstrate how modern methods of construction can deliver construction projects faster, better, safer, greener and more cost effectively.

Figure 15 Pre-assembled strongbox core component with integral stairway (courtesy Landsec)

Case study 7 (contd)

The pioneering approach was supported by UKRI Innovate UK who awarded Landsec, Bryden Wood and Easi-Space an R&D grant in 2019 to help to develop and prototype the innovative superstructure system. The Forge was also selected by UKRI Innovate UK as a demonstrator project for the Transforming Construction Challenge in 2020 with the aim of proving the value and potential of the P-DfMA approach to improve productivity in the construction sector.

Productivity improvements have been demonstrated through the application of BIM and DfMA methodologies, optimisation of the superstructure design and the application of automated construction processes, minimising the need to work at height and using a multi-skilled workforce.

The project has also won awards for its innovative use of technology securing the Digital Construction Project of the Year and Digital Innovation in Offsite Construction at the Digital Construction Awards (2022).

Figure 16 Temporary works in place at the Forge (courtesy Bryden Wood)

The social cost of carbon

6

Nigel Fraser, Buildoffsite

Measuring GHGs in tonnes throughout the life of an asset is one thing. It is increasingly being recognised that the social cost of carbon (SCC) also needs to be evaluated as part of major investment decisions, particularly with respect to infrastructure funded by governments.

For this purpose, the UK Government values carbon in 2022 at 245 £/tCO_2e (rising to £252 in 2023 and £378 by 2050) when assessing energy use and GHG emissions.(27, 28)

This trend is not exclusive to the UK. In the USA, government policy requires investments to be evaluated in terms of the SCC. In February 2021 it set the SCC at $51 per tonne (using a discount rate of 3%).(97)

On a related note. The EU's carbon credits, allocated to companies, are trading at around €100 per tonne at the time of writing.(83)

Avoiding loss of invested carbon due to corrosion

Corrosion is a whole life cost and whole life carbon issue as expensive repairs are needed to replace before investment in carbon intensive products with often more high-carbon materials (eg Portland-based cements and steel). Corrosion is a big issue and will get bigger if steps are not taken to plan for its avoidance, management and control.

How big an issue? NACE International have estimated that asset degradation amounting to US$2.5 trillion of repairs to be carried out on infrastructure and buildings has been caused by corrosion. This surprisingly high (if largely hidden) cost represents about 3.4% of global GDP. The NACE IMPACT study estimates that by using available corrosion control practices, 15 to 35% of this could be saved.(29) This strongly suggests that there is already a case to change the way assets are designed and operated.

With climate change affecting the planet, the reasons become even more compelling. Atmospheric CO_2 levels are rising and more extreme weather events are becoming more frequent – both are linked to corrosion. Specifications and designs need to evolve to permit a more proactive approach to control for whole life performance, particularly if design lives of 120 years without major repairs are required.

Buildoffsite's Achieving sustainable resilience in new precast concrete structures(30) highlights a range of innovations that are available to do things differently (see **Example 7**).

Appendix A1 provides further information on this important area of whole life carbon including a description that gives different perspectives on how it is measured and how it may be minimised.

Example 7

Climate change – doing things differently

Incorporation of low-carbon corrosion prevention technology into precast concrete elements from new, to assure whole life carbon and whole life cost are optimised. This may be used in targeted or perceived to be vulnerable or difficult to access areas where there is higher risk of water or salt ingress or throughout structures to provide greater assurance.

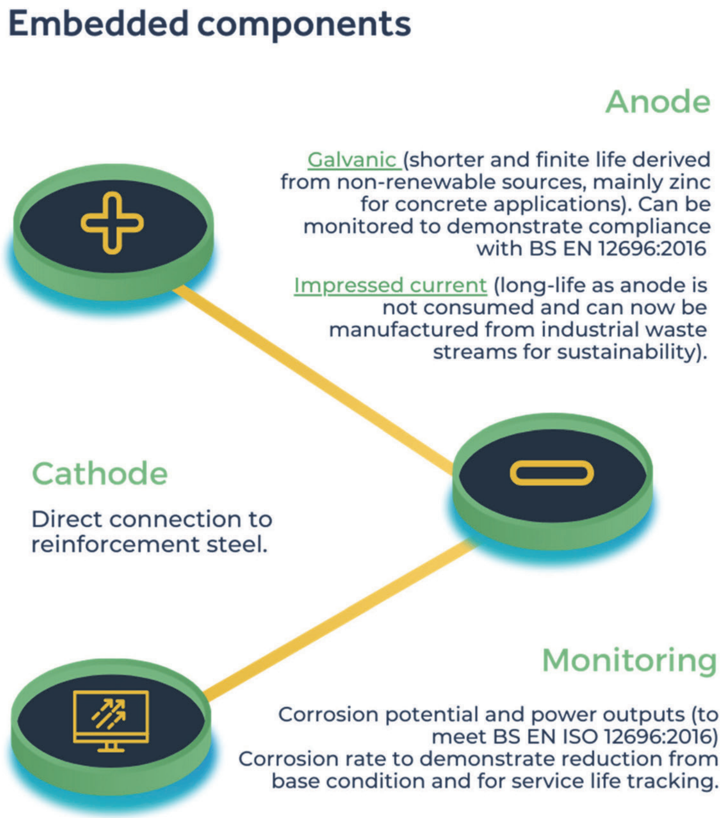


Figure 17 The components of a designed cathodic protection system

Example 7 (contd)

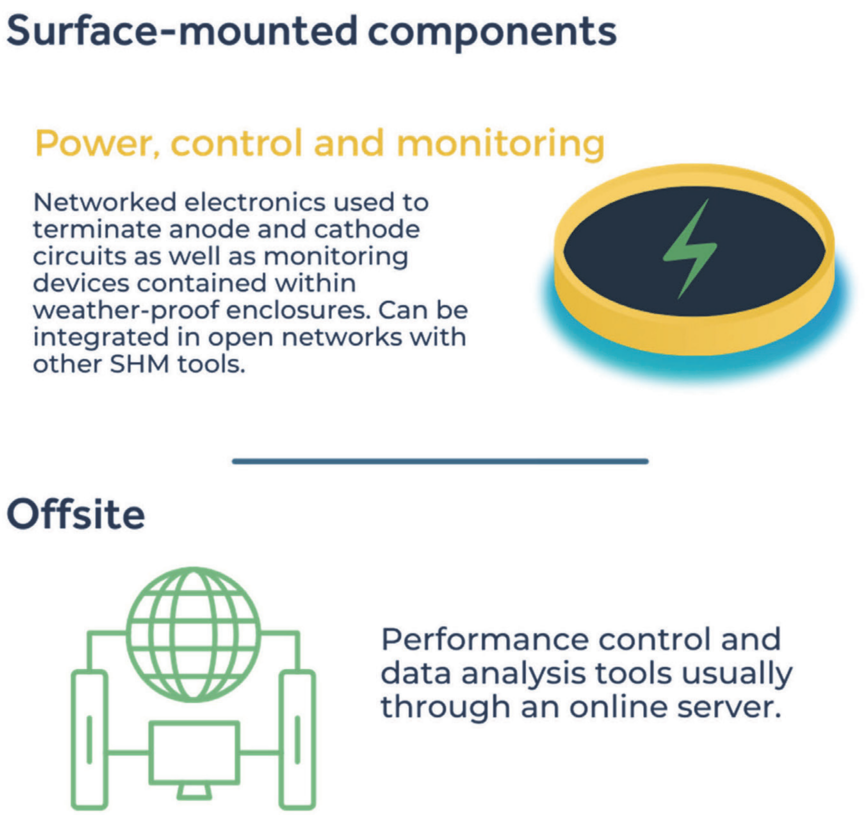


Figure 17 The components of a designed cathodic protection system (contd)

Example 7 (contd)

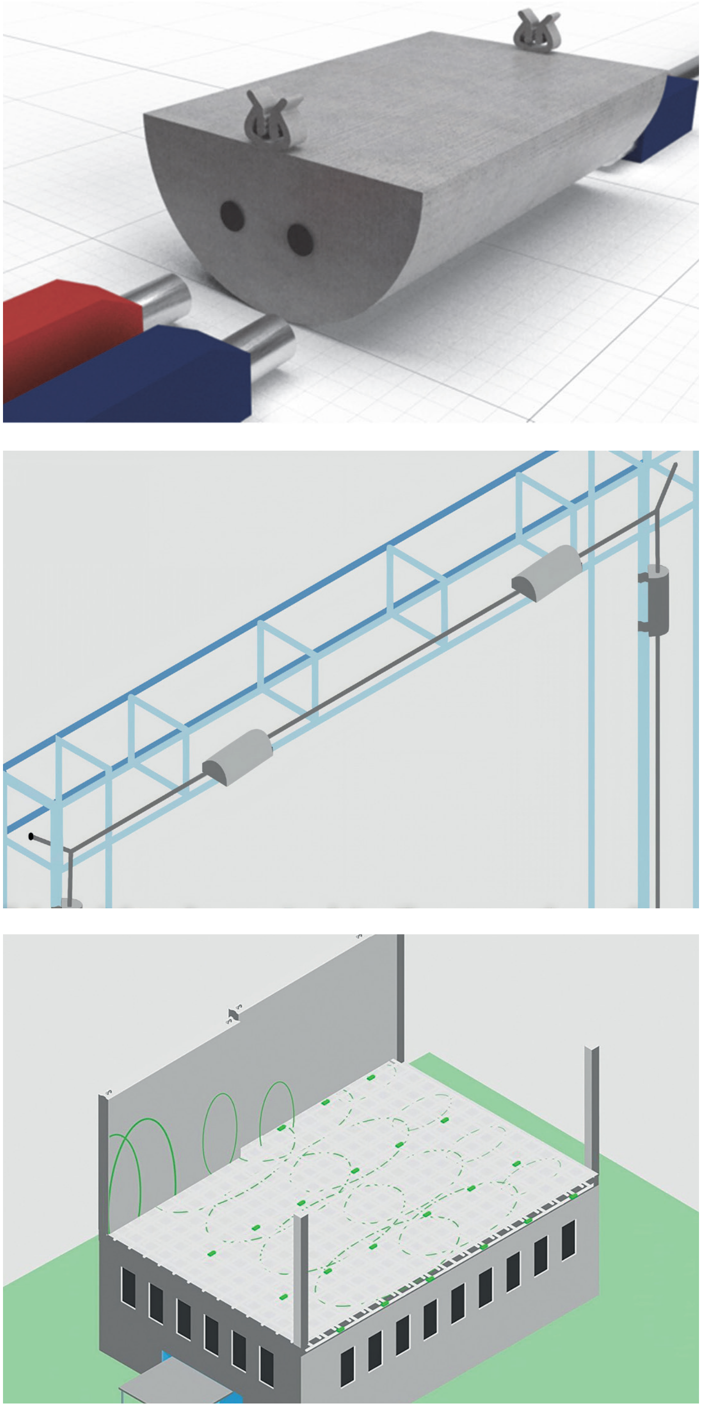


Figure 18 Modular anode unit (MAU) and wiring using LoCem, designed for easy assembly in factory or on site (other anodes are available) (courtesy C-Probe Systems)

Example 8

Change to low carbon concrete mapped out[21]

The Green Construction Board's Low Carbon Concrete Routemap[21] provides a route to reducing carbon emissions over the coming decades. Incorporation of low carbon concretes into offsite products has the potential to demonstrate early adoption of innovations.

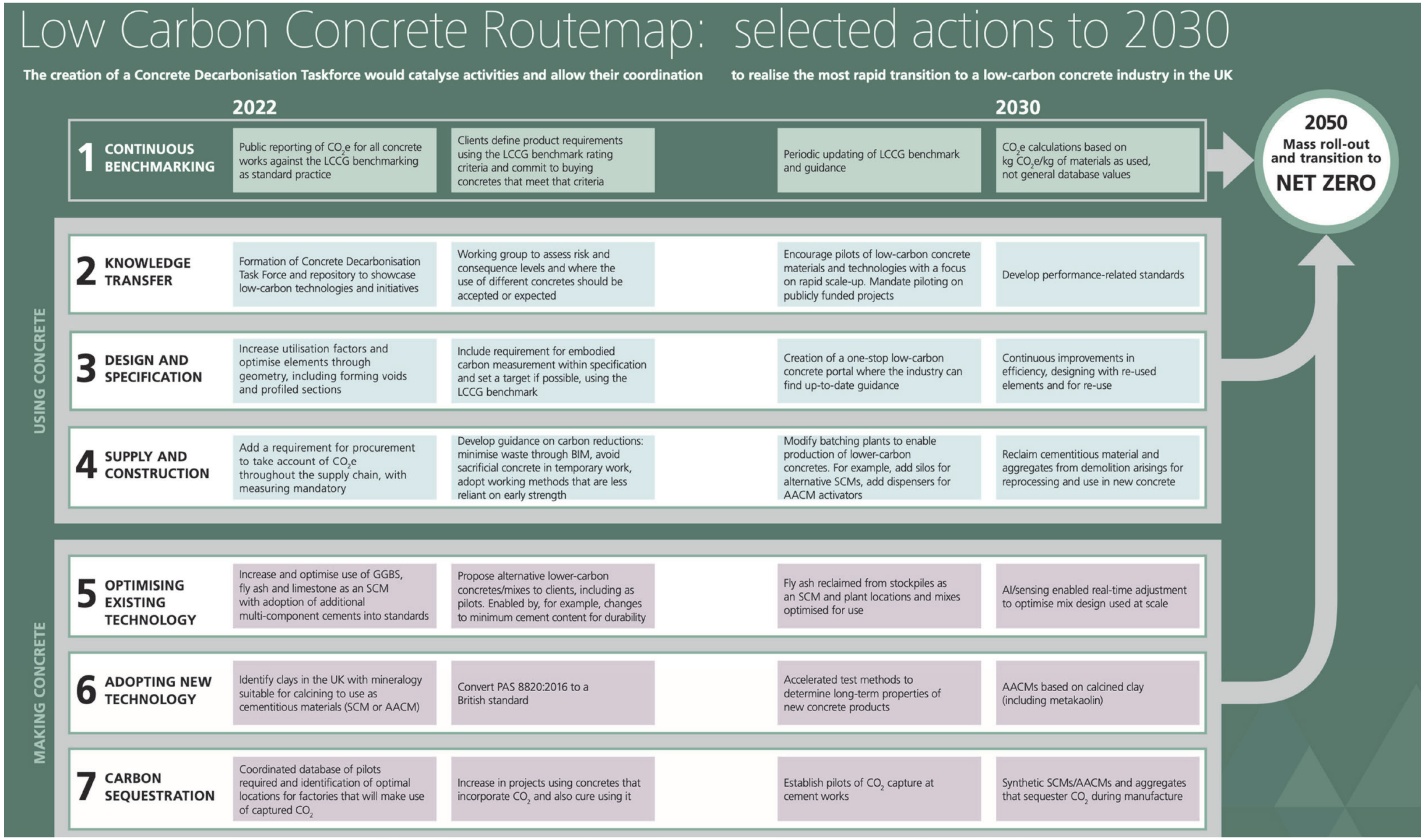


Figure 19 Low concrete carbon routemap (courtesy ICE/GCB)

Case study 8

3D concrete printing at Houghton Brook

Benefits of 3D printing

- The printer uses 40% less materials and the failure rate is lower, optimising the materials used; the product is designed to maintain structural stability while reducing material volumes.
- A controlled process with no formwork and reduced on site installation means less waste and a lower carbon footprint overall.
- Reduced transport to site (lower carbon, cost, disruption and health and safety benefits).
- Quicker construction.

Figure 20 Delivery, installation and completed 3D concrete printed staircase (courtesy Environment Agency)

Programme and project planning

7

Nick Hacking and Tom Kyle, Sheppard Robson, with contributions from Buildoffsite members in the infrastructure sector

Introduction

For a project to realise the full potential of MMC consideration and integration of available technologies need to be professionally managed and part of the project programme from the inception. There will need to be more awareness of the potential that offsite/MMC can offer and with that a greater commitment to the industry from the start and throughout the design and procurement process.

Planning for offsite/MMC will require a new approach, one that has its core ideas embedded in the design process and programme of decision making. The approach should work closer with manufacturers and suppliers to provide a greater understanding of the possibilities, suitability, and constraints of the available systems. It should work to enable a smoother design process with less duplication of design and re-work of the initial intent. In this way, offsite/MMC will become part of the process and not (to some) an unwanted post planning application. It is hoped that there will be a shift away from the negative connotations as a dilution of the original (traditional) design concepts to designs that celebrate the quality and richness that offsite/MMC can deliver.

The critical difference to planning for offsite/MMC is the need for significantly more technical awareness at the early stages of design. Teams should be assembled and structured to bring a suitable level of technical input and ensure the full benefits are captured at the initial stages of the project, consideration should be given to appointment of a specialist offsite/MMC consultant (MMC advisor) and the ultimate value they might bring to the project. The traditionally held perceptions of the design workflow and decisions required at the various RIBA work stages will need to be reconceived, there will need to be more continuity and commitment to the design team and a re-linking of the pre and post planning design stages, the separation of which has brought about a fracturing of the process in recent years. Only in this way will there be a long overdue increase in efficiency in the design process, standardisation and continuity of digital information and more predictable project programmes, procurement and construction of buildings.

To extract the biggest programme benefits using MMC/offsite, designers should consider the lean construction approach of balancing the erection time of major elements as they are delivered to site. This is probably easiest to envisage with a high-rise building in which a structural core is being formed, floor by floor, while at a lower level, weatherproof volumetric modules are being placed to build out the floors, possibly including the façade and, in some cases, fully furnished rooms. An internal study by BAA for the efficient construction of airport piers balanced the assembly times for portal frames, floor cassettes, roof cassettes, and cladding, enabling significant programme savings.

This chapter sets out considerations in respect to offsite/MMC at the various stages of the design programme broadly relating to the RIBA Plan of Work,[84] while also considering infrastructure. The technology and solutions now available to the industry are vast and rapidly changing, this chapter provides a broad summary with key examples rather than a comprehensive itinerary of offsite/MMC application.

Integration of offsite within concept design

A thorough evaluation of offsite/MMC is crucial at the early stage of the design process to capture initiatives that will bring the most benefit before it becomes too late and disruptive to the design to include. Undertaken in parallel with the brief preparation and site feasibility, offsite/MMC may be the only viable design solution for a particular site or brief aspiration. The project programme should allow for this evaluation at RIBA Stages 0 to 2 or equivalent infrastructure project planning methodology stages before the design concept is fixed.

The range of available offsite/MMC solutions and the technology to easily adapt and provide bespoke solutions is constantly expanding. It is important to appreciate from the outset that using offsite/MMC is not a determinant or restriction to the architectural expression but can offer the same if not more freedom in finding the most suitable response to the brief and site.

Strategic aims of offsite/MMC

Crucial to informing the strategy to offsite/MMC are the strategic aims of the projects. What is most important? Programme, environmental impact, cost, quality, long-term management or (and most likely) a combination of these. The strategic emphasis for a particular project will drive the agenda, the project may be part of a wider programme of projects which will make getting the right solution for the prototype more important. Possible strategic aims and the related MMC are set out here and illustrated in Figure 21. These objectives and solutions should be mapped out at RIBA Stages 0 and 1 or equivalent infrastructure project planning methodology stages to inform the project brief and site feasibility.

- **Environmental agenda** – lightweight and timber structure/façade systems and low-carbon concretes and steel production methods to save embodied carbon. Volumetric modular or unitised façades to enable better passive measures such as higher air tightness and solar performance, along with reduced site transportations and waste associated with both buildings and infrastructure projects.
- **Long-term performance** – pods, prefabricated services and volumetric modular provides higher levels of quality control allowing for more systematic engineered solutions, offering long-term performance and maintenance benefits.
- **Unlocking a constrained site** – volumetric modular or lightweight structural systems will reduce the site programmes, logistics and labour, providing solutions for sites with difficult access, compromised ground conditions or high-risk boundary conditions. Offsite solutions can also reduce impacts upon neighbours for both building and infrastructure sites.

- **Constrained viability** – a standardised approach to pods/modules, prefabricated services, precast components and volumetric modular can all reduce cost provided there is sufficient repetition, and the design of the elements are kept close to an industry standard.

Once the strategic aims and priorities are well understood, further detail on the nature of the project should refine the choice of solutions. The greatest influence is likely to be the building/asset use and the site constraints. The possibilities and their suitability to the project specific needs should be evaluated in parallel with the feasibility and development of the design concept (eg RIBA Stage 1 & 2 or similar).

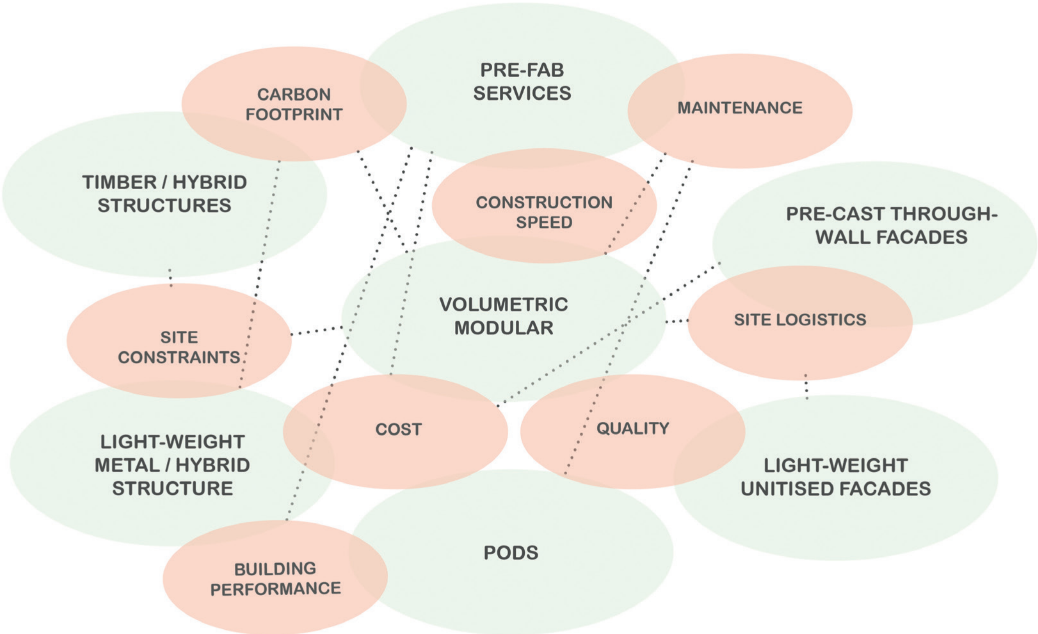


Figure 21 Selecting the right MMC solution to meet the strategic aims (courtesy Sheppard Robson)

The right solution for the project

Each use class will have different spatial and functional requirements, they will have differing technical and regulatory demands and they may also have very distinct social or political agendas. All of which will influence the approach to offsite/MMC, and the suitability of the solutions considered. Some factors can be quite obvious – the cellular nature of hotels is great for volumetric modular, but other factors may require a more in-depth technical understanding more of which is covered in the following section. A broad (non-exhaustive) outline of the main use classes and how they may influence the choice of MMC is provided here and illustrated in **Figure 22**.

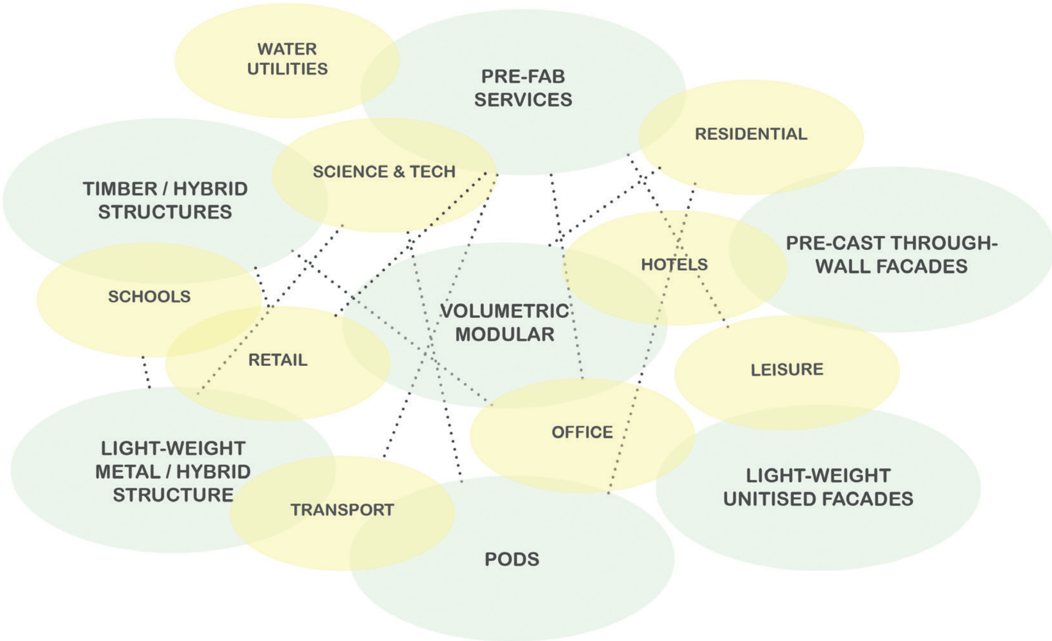


Figure 22 Selecting the right MMC to suit the project type (courtesy Sheppard Robson)

- **Residential** – pods and prefabricated mechanical, electrical and plumbing (MEP) cupboards becoming standard for mid to large schemes. Volumetric modular where sufficient repetition and the site value is not too high (there is a slight loss in plan and sectional efficiency). Unitised façades to meet increasing envelope performance standards. Caution with use of timber and lightweight structural systems in relation to fire and acoustic test certification.
- **Office** – timber/hybrid structure offer large spans for open floorplates and lower carbon footprint, unitised façades will provide high levels of envelope performance.
- **Schools/education** – use of timber will provide improvements to student health and learning ability. Timber/hybrid structures will provide large spans needed, Volumetric modular or panelised systems suited to repetitive classroom design.
- **Hotels/student accommodation** – ideal for volumetric modular if rooms are sufficiently compact for transport restrictions.
- **Healthcare facilities** – adoption of platform construction techniques using a range of Category 1 to 3 forms to accommodate the range of existing and new build requirements.
- **Custodial estate** – benefiting from consolidating requirements across projects and sharing learning across supply chains, particularly with respect to precast concrete solutions and MEP modules.

- **Retail/leisure** – increase in OSM (panelised wall systems and prefabricated services) will reduce site programmes and may allow for part of the site to continue to operate and trade, hybrid structures will offer larger/lighter spans.
- **Transport** – prefabricated structural systems, bridges, viaducts, tunnels, platforms, engineering services and building elements will provide solutions to constrained and active transport infrastructure sites.
- **Science and technology** – highly serviced and sterile environments will benefit from prefabricated services and volumetric modules in particular. Reconfigurable modular walling systems also provide flexibility as requirements change.
- **Utilities infrastructure** – from modular nuclear power stations and wind turbines to prefabricated MEP modules (eg to standardised Water Industry Mechanical and Electrical Specifications, WIMES) and a wide range of precast products (tanks, large diameter sewers etc).

The right system for the site

Recent advances in building technologies are unlocking solutions to sites where redevelopment had previously been considered too constrained or cost prohibitive. Offsite/MMC can allow critical functions of adjacent sites to continue during construction, but it can also be sufficiently adaptable and tailored to address sensitive urban or sub-urban townscapes. A broad outline to the suitable MMC for a range of site conditions is provided here and illustrated in **Figure 23**.

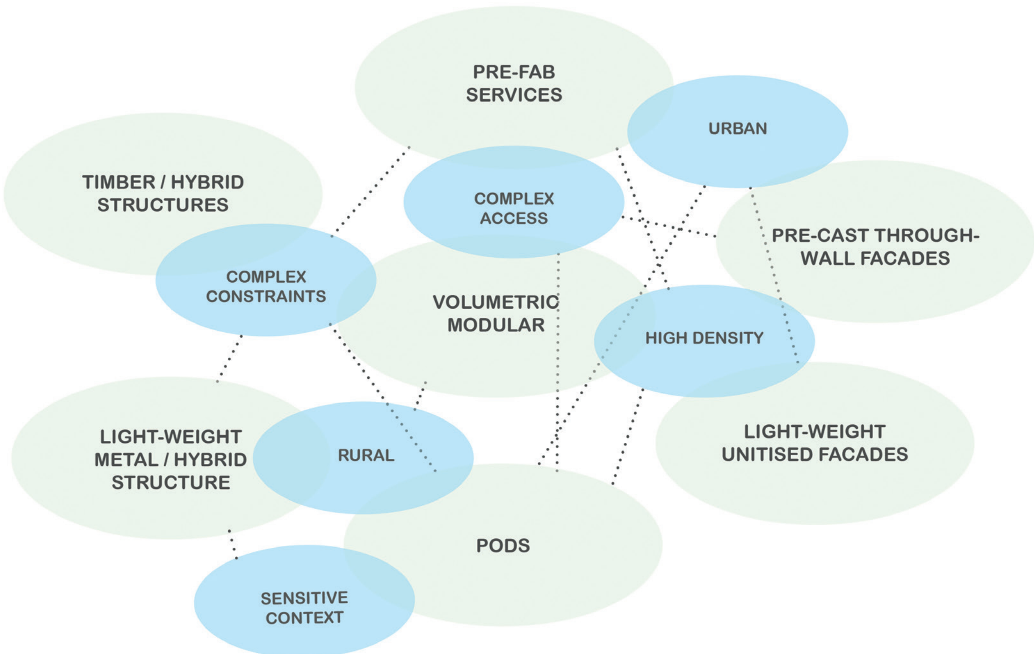


Figure 23 Selecting the right MMC for the project site (courtesy Sheppard Robson)

- **Highly constrained** – adjacent or on top of rail lines/main roads and sites with constrained access will benefit greatly from reduced construction programmes and site labour with use of volumetric modular or as much offsite prefabrication as possible for the project. Precast structures and panelised façade systems can open up sites close to roads and pavements. New scaffolding and fall containment systems can help too. Bridges and gantries may be lifted into position during night-time possession.
- **Dense urban** – can be more prohibitive to volumetric modular or large pre-fabrication due to complexity of getting the elements to site, volumetric modular can be limited to approximately 20 floors. Use of prefabricated structural systems or pre-assembled pods will reduce site transport and labour. Roof level plant rooms are often delivered as modules with limited road closures in quiet periods.
- **Sensitive townscape** – volumetric modular or unitised façade systems, for both buildings and infrastructure, can provide good quality solutions as long as care is taken in the selection of the manufacture/supplier that can provide sufficient adaptation to the bespoke requirements.
- **Rural** – with easier access and more space to apply a standardised solution there is likely to more scope for fully volumetric modular or large-scale prefabrication of structural and internal elements. This applies to both buildings and infrastructure projects.

Integration of offsite within the spatial co-ordination and technical design

Designing for the integration of offsite methods of construction need not be a constraint on the design. Many of the principles are aligned to good design. Structural grids should be optimal and repetitive and aligned to space planning of the building. Floorplates should be stacked with structure and services aligned vertically through the building. Façades should be repetitive using standard dimensions. Linear structures (eg airport terminal buildings, station platforms, tunnels, viaducts) should adopt similar approaches in the horizontal plane. These good design principles will lead to a number of benefits no matter what the method of construction:

- A good form factor will maximise thermal performance with good detailing for air tightness and minimising thermal bridging and minimal heat loss and gain.
- Repetitive elements can generate efficiencies in material use reducing waste and minimising embodied carbon.
- Constructability is enhanced reducing risk and providing greater programme certainty.

At this stage of the project these key principles should be enshrined in the design, and the challenge is to retain the design concept through structural and services co-ordination. This may require additional tolerance to be designed in to allow the flexibility to choose different offsite solutions through procurement.

Some other key design considerations:

- Choose off-the-shelf products, such as standard door-sets, staircases, lifts and windows etc.
- Design for standard product dimensions such as the dimensions of plasterboard, timber or precast beams etc.
- Do not overly constrain services zones enabling the use of standard ducts, pipes etc.
- Use a performance specification where possible allowing flexibility in procurement.
- Use BIM and ensure that the whole design team follow from the same model.

Volumetric modular (Category 1 – 3D primary structural systems)

This category of MMC is most suited to short span cellular repetitive building types such as hotels, student housing, temporary buildings, and residential both houses and flats. The repetitive nature of the building generates the economies of scale, and the short spans allow whole modules to be transported by road. They can also be useful additions to existing buildings where disruption is to be avoided.

Transport of volumetric modules

Volumetric modular systems are restricted by the capacity of a lorry. The maximum width for a lorry is 2.55m, however most rooms widths are greater than this, so a wide load is to be expected, the wider the load the more onerous the requirements. It is recommended to design for widths – spans around 3.6 to 4m. The maximum length of a lorry is 12.3m,

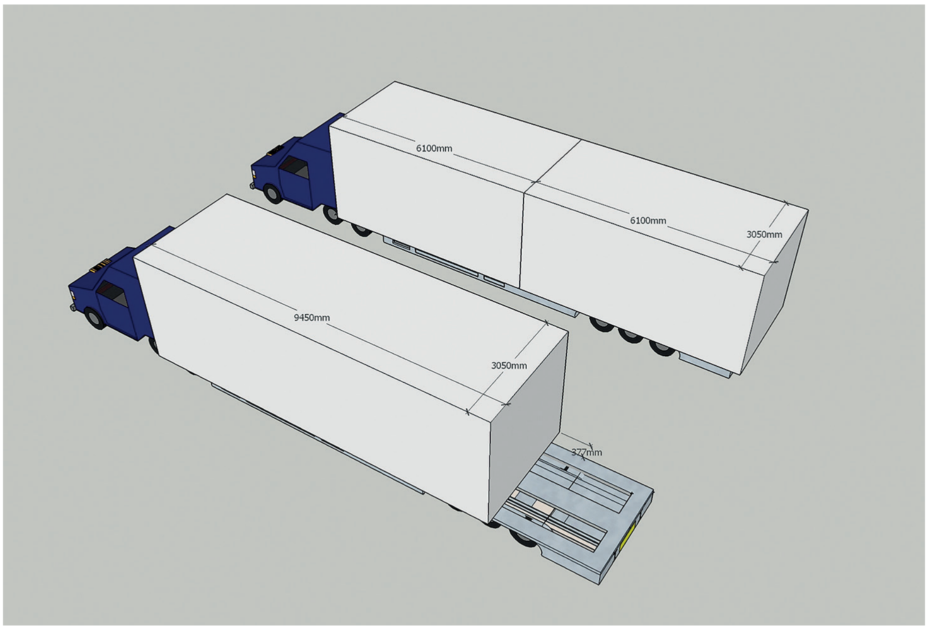


Figure 24 Modular transport constraints (courtesy Sheppard Robson)

and again the load can overhang the rear. It is recommended to avoid exceeding 15m in length. The height should be kept below 4m which would be suitable for most building and infrastructure module types.

Floor-to-floor heights

The floor-to-floor height normally exceeds that of a traditional system for the simple reason that a volumetric modular system needs to have a roof and a floor structure at every level. This should be included at the planning stage of a project to ensure that there is flexibility at procurement to allow for a slightly taller building.

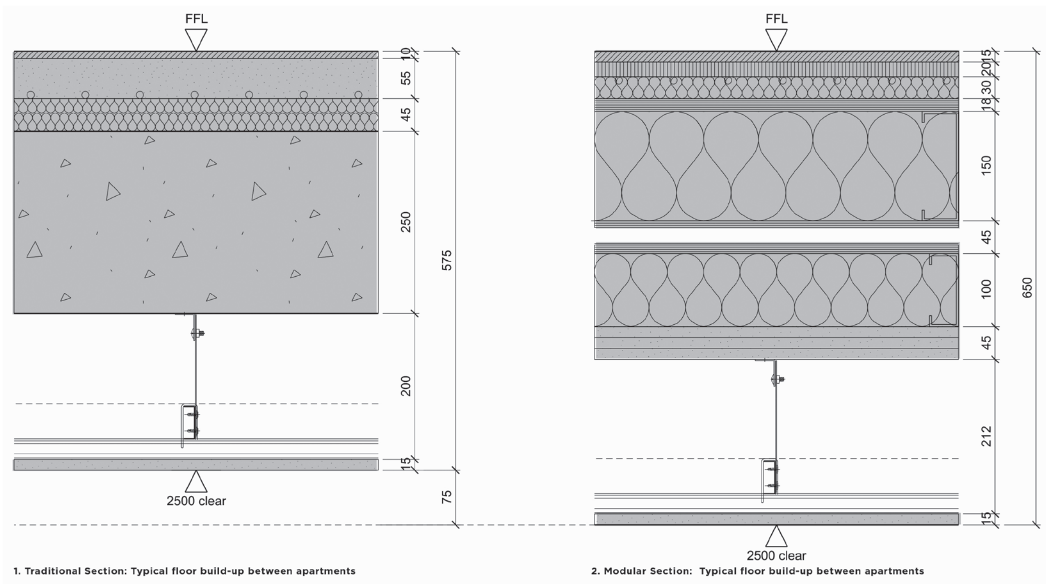


Figure 25 Comparative floor/ceiling constructions (courtesy Sheppard Robson)

Wall thickness at module junctions

When volumetric modules are placed side by side, the wall is doubled up, which is well suited to a party wall which needs the acoustic break and the fire separation. Hotels and student housing require this between every room. In residential design rooms within a house or apartment typically have 100mm stud wall partitions. In a volumetric modular scenario, all the module walls are approximately 300mm, which means the wall is over engineered for its use. Where possible module joints should be located along party wall lines, which are already 300mm thick. In an apartment block over half the walls that would be module joints are only internal partitions, so there would be many internal walls that would become thicker than traditional construction, which would increase the footprint of the building. The red lines in **Figure 26** represent the plan using modular construction.

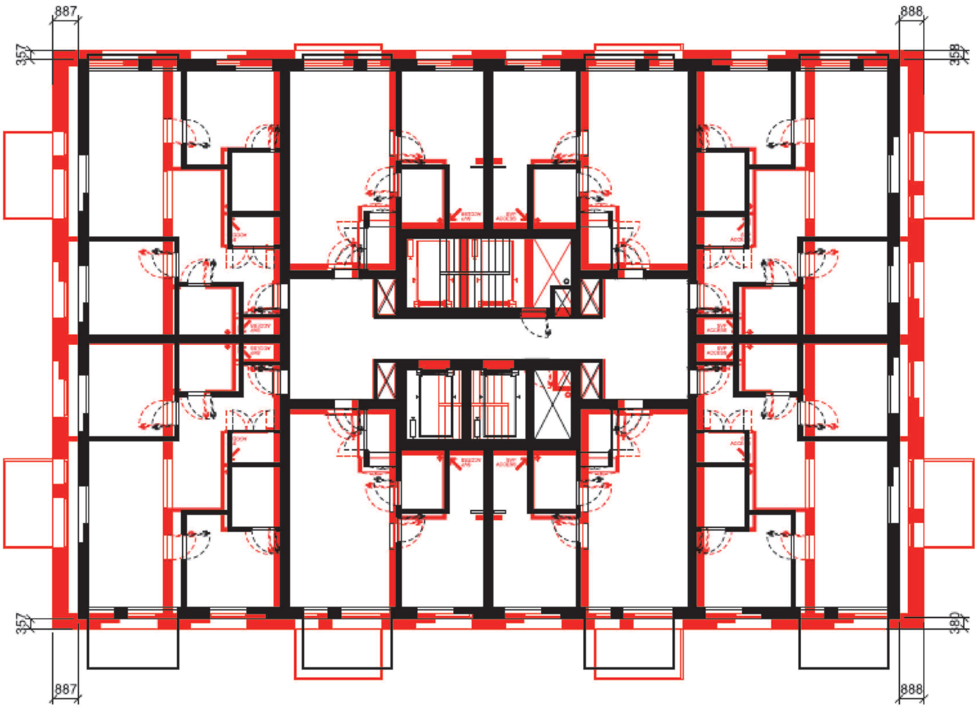


Figure 26 Building footprint comparison between traditional (black) and modular (red) (courtesy Sheppard Robson)

Building height constraint

Innovation in modular construction has led to some very tall buildings capable of being built, with recent examples in London of up to 50 storeys. The stacked nature of the floorplan of a tower is ideally suited to the repetitiveness of modular construction. As the building gets taller, structural section sizes increase which will affect the net to gross efficiency, and construction logistics will demand consideration of connection points.

Service connections

Volumetric modular construction is at its most efficient when the whole module (eg hotel and student rooms) is fitted out in the factory. Flats' layouts will always be made up from multiple modules, so services inevitably will need to cross the modules. These crossover points will need to be designed in a single location, ideally the hallway without a ceiling, so that the connections can be made, and ceilings finished off with minimal effect on the rest of the apartment.

Movement joints

Movement between modules needs to be considered when designing the façade. There needs to be enough flexibility in the façade system to allow for vertical and horizontal movement without affecting the water-tightness or fire stopping.

Interface of balconies in residential buildings

Modular buildings can support cantilevered bolt-on balconies which would be installed separately to the module. The primary structural elements to a volumetric modular building are on the corners, so it is most efficient to align the balconies to the width of a module.

Prefabricated structural systems such as CLT, pre-cast concrete, lightweight frame and load-bearing panel systems (Category 2 – 2D primary structural systems)

These systems are ideally suited to repetitive building types with longer spans such as offices and schools, and infrastructure. In each case onsite programme time is much more critical and these systems can bring significant benefits.

Figure 27 Churchyard Row CLT residential building (courtesy Sheppard Robson)

Layouts to be co-ordinated with maximum spans

To maintain flexibility to use a panel system with load-bearing walls, it is important at planning stage to consider the constraints of these systems. Floorplans need to stack with minimal variation, and layouts needs to be kept rational with regular spans. In the case of school design, it is worth designing and agreeing the room arrangements and stacking from at the outset, so the standard module can be repeated around the site. The more consistent the span, the more efficient the system and floor build-up will be. It is also important to consider the most efficient span for each system. In the case of wall panel systems, the length of the panel should be optimised for the length of the lorry that is transporting them.

Panelised systems can be combined with highly serviced structural volumetric modules (eg for kitchens, bathrooms and lift shafts or service risers in commercial buildings) to configure larger spaces than volumetric modular would provide for within the practical transport limitations. Panelised (or cassette) based concepts have also been developed for long, low-rise buildings, incorporating multi-functional and serviced, wall, floor and roof cassettes.

2D precast components are also widely used in a range of infrastructure contexts, such as bridge decks and pre-tensioned, hollow core planks.

Fire regulations

Where a wall is load bearing and also a compartment, there are more restrictions on its design and installation. Suitable linings need to be allowed for which must have minimal, protected, penetrations to prevent compromising the integrity of the wall.

Unitised and panelised façade systems

Unitised façades can offer benefits in terms of speed and safety of installation, and quality control and airtightness. The greater the repetition, the more cost effective it becomes. Office buildings are well suited to this and the floorplate behind is often open plan which places fewer constraints on the setting out of the façade grid. Care needs to be taken in design to ensure that the panel joints are aligned to fixing points, such as the top of slab edge. The panel also needs to be designed to take into consideration how it is transported and lifted. It is also important to consider the provenance of the materials being selected, how they are finished and how they are assembled to minimise transport.

With all façade typologies, their level of integration with the structural frame is important to recognise early in order to achieve the maximum benefits of offsite construction and MMC. Co-ordinating fixing points, cast-in channels and, most importantly, tolerances between elements are crucial to the success.

In developing offsite solutions for façade construction, a critical appraisal needs to consider the follow aspects:

- The briefing requirements and minimum performance, ie are there sustainability or embodied carbon targets or specific performance standards (eg infrastructure blast protection) that may affect the form of façade or materials used?
- What are the site logistics constraints, ie what is the maximum module that can be safely delivered and lifted into final position? Will the façade panels adversely impact on hook-time/programme?
- What are the lead-in times (this is particularly crucial when considering load-bearing façade typologies)? Is there sufficient capacity and storage on site for panels to ensure that the frame construction is not disrupted?
- Aesthetics – are there particular planning requirements?
- Temporary works – are there temporary requirements that will shape the design, ie lintel requirements to maintain panel rigidity while lifting?

Preassembled partitions need careful consideration from the early stages of a project as these may need to be co-ordinated with the installation of the structural frame. Equally, preassembled door and screens need careful logistics review to ensure that these can be progressed into the final position and installed. However, internal fit-out can represent a significant proportion of the project programme so any improvement is worth consideration.


Figure 28 Bathroom pod (courtesy Sheppard Robson)

Bathrooms and WC pods and pre-assembled kitchens (Category 5 – non-structural assemblies)

WC pods and pre-assembled kitchens

In large projects bathroom pods are becoming more commonplace, for example, housing, hotels and student accommodation. Bathrooms and wet areas are elements of a building where quality control is critically important. They are also fairly confined spaces and require many different trades, so if the entire room can be built, tested and finished offsite then it can offer benefits of better quality, and reduced labour on site.

Bathroom pods need to be considered by the design team at an early stage in a project. At concept design stage, the number of bathroom types need to be kept to a minimum and the dimensions agreed at the outset. At spatial co-ordination and technical design stage, there are some key watchpoints for designers to ensure that bathroom pods are a viable solution.

Bathroom pods are self-contained, so they have their own floors and ceilings, and enough space needs to be allowed for in the floor and ceiling build-up for them. Consideration needs to be made to construction sequencing, to ensure they can be installed quickly and simply.

For space planning they need to be installed next to a soil stack, and the connection should be made on site before the dry lining is completed; care must be taken to avoid placing the stack next to a structural column, which would prevent access for the connection. Try to avoid placing pods back-to-back as this would make the second pod hard to install. Finally, if the pod is next to a party wall, make allowances in the floorplan layout for the party wall and the pod wall side by side. Make allowance for the outer lining and onsite services around the outside of the pod.

Many of the benefits of bathroom pods also apply to utility cupboards for residential projects. They are confined spaces with the majority of the mechanical and electrical equipment inside.

Designers need to consider how they are installed and make allowances for the services connections above and the floor below. They need to allow for the double wall when they are next to a party wall.

Again, they can offer significant benefits from quality control, pre-commissioning, and space planning all done offsite.

Procurement, manufacture and installation

Barriers and reluctance to adoption of offsite

As has already been demonstrated in this guide, the use of offsite construction methodologies can bring a broad spectrum of benefits to appropriate projects. Despite this, however, reluctance to the use of MMC in favour of traditional approaches is still common. The number of global OSM and systems is limited, which can lead to concerns regarding product and material availability as well as long lead-in times, but the number and variety is steadily increasing.

Another barrier to adoption of offsite technologies is the high dependency of a main contractor on a single offsite subcontractor to deliver a large portion of a project. The associated risks of supplier insolvency, delays, loss at sea etc can lead to contractors putting their eggs in more than one basket and be disinclined to depart from tried and tested methods of working. Offsite accreditation schemes such as BOPAS (see **Chapter 10**) provide assurance underpinned by a warranty provision to alleviate such concerns.

"There is a perception that the product is low quality and has no integrity of design, but that simply isn't the case now," Wayne Oakes, of multi-disciplinary engineering consultancy Dice explains.[32] Alan Shingler, Partner at Sheppard Robson, writes: *"Prefabrication is a process not an aesthetic; MMC does not have to limit architectural ambition or curtail quality. Often there is an assumption that modular buildings will look repetitive, with the pre-formed elements defining the architectural character of the building."*[32]

Buildings such as Sheppard Robson and Concrete's citizenM hotel next to the Tower of London are helping to remove the negative image of offsite construction[34]. Through its carefully considered façade composition, the AHEAD Europe 2017 award winning project is a volumetric modular building with a high-quality façade within the context of a conservation area and a UNESCO World Heritage Site.

With regards to the residential sector, Oakes says that there is *"…a real lack of knowledge within the sector about modular and this reluctance to learn is stunting innovation and growth … ultimately preventing us from building more homes more quickly."*[32]

Procurement

To maximise the advantages of offsite construction the early appointment of a manufacturer is essential, and the earlier the better. The RIBA DfMA Overlay to the Plan of Work[85] recommends that offsite opportunities are considered from RIBA Stage 0, and an offsite advisor is appointed by Stage 0.

Gary Cawley, director of North & Central England at Consortium Procurement Construction explains: *"You are going to need a two-stage tender process, with an initial pre-contract service agreement (PCSA) with a MMC supplier who can help you with a proper site investigation, designs and budgeting, and with whom you can go through planning together. Through a better approach to sharing and minimising risk, you'll reap significant benefits later on."*[35]

Case study 9

citizenM Hotel, Tower of London, designed by Sheppard Robson using Polcom Group's volumetric modular system

Overview

The global flagship citizenM hotel provides 370 volumetric modular bedrooms over nine floors. The site posed significant technical and logistical challenges given its location to the north of the Tower of London (a UNESCO World Heritage Site), within a conservation area, next to listed buildings and the Roman London Wall. The building sits directly above the London Underground station of Tower Hill and takes support from some of the retained structural columns from the previous building that occupied the site. The lightweight nature of volumetric construction enabled

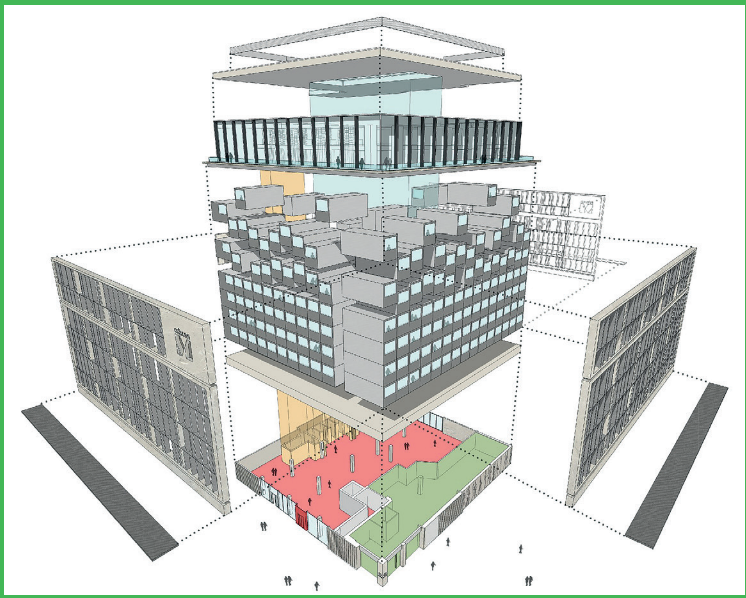


Figure 29
Modularity of the building

Case study 9 (contd)

a nine-storey building to replace the former six-storey development. citizenM's signature bedroom design was used to create a standardised and highly efficient floor plan, with bedrooms laid out around a central courtyard. This project was awarded winner of 2017 AHEAD Europe Best Urban Hotel – Newbuild Award.

MMC solution

Volumetric modular construction was a perfect match for both the hotel typology and the highly constrained central London site because it enabled the bedroom modules to be manufactured off site, complete with windows, internal finishes, fixtures, fittings, and first-fix services, before being transported. Due to the unique proportions of the citizenM bedroom, two bedrooms, connected by a central corridor, were combined into a single module. The volumetric construction also delivered a very high-quality finish and facilitated offsite acoustic testing, weather testing, defect identification and rectification, as well as reduced construction waste when compared with traditional methods. The contractor, Balfour Beatty, ensured that module lifting operations were carried out at night.

Figure 30 Lifting a room module into place

The elevations feature hand-set Portland stone (a town planning requirement given the architectural context), precast concrete panels with Portland stone facing, standardised GRC fins (which reduced the cladding weight by over 200 tonnes compared to precast concrete), horizontal anodised aluminium extrusions, DGU windows and anodised aluminium curtain walling. Support for the stone and GRC cladding was taken largely from the modules themselves.

Figure 31 The resulting citizenM Hotel

Case study 10

East Wick + Sweetwater MMC/standardisation

Innovation

Sheppard Robson have collaborated with AStudio to deliver a standardisation project which has developed housing typologies and building fabric to support delivery via reinforced concrete (RC) frame, light steel frame or fully modular volumetric construction. The project is innovative as it enables detailed design issues to be solved by a team comprising designers, engineers, constructors, specialist suppliers, cost planners and other stakeholders. This ensures that a costed design solution for key elements of the building, fully co-ordinated with the energy, sustainability and sales and marketing strategies can be provided for the designers of each parcel before the planning scheme is developed. The choice of construction system provides flexibility – the client will deliver the next phase in RC frame in order to maintain their programme with time to engage a modular supplier to deliver Phase 3 onwards. The standardisation has been delivered in Building Information Management (BIM) to create a virtual warehouse of pattern book solutions.

Figure 32 The site

Project overview

1100+ new homes at the Queen Elizabeth Olympic Park, Balfour Beatty and Places for People

The client wanted to exploit the opportunities offered by a long-term multi-phased development by ensuring that the design had the capacity to be delivered as volumetric modules. The strategy adopted enabled Phase 2 to be delivered as RC frame with prefabricated sanitary accommodation pods initially creating time in the programme to ramp up to modular delivery for subsequent phases.

Case study 10 (contd)

Sheppard Robson have experience delivering modular projects and collaborated with AStudio to develop a pattern book of apartment types with a standardised approach to the building fabric for modular delivery. Phases 3 to 6 have received planning approval based on a fully volumetric design.

The consultant team developed the design to address the constraints and requirements imposed by the construction method and, working with the project management team, undertook an extensive supply chain engagement exercise to validate the design across key issues:

- Fire safety specification and testing for buildings over 18m.
- Integration of building services to suit constrained space allowance for service voids, optimising storey heights within planning constraints.
- Application of lightweight cladding suited to modular systems covering brick slip, rain screen and glass reinforced concrete (GRC) offering a rich materials palette.

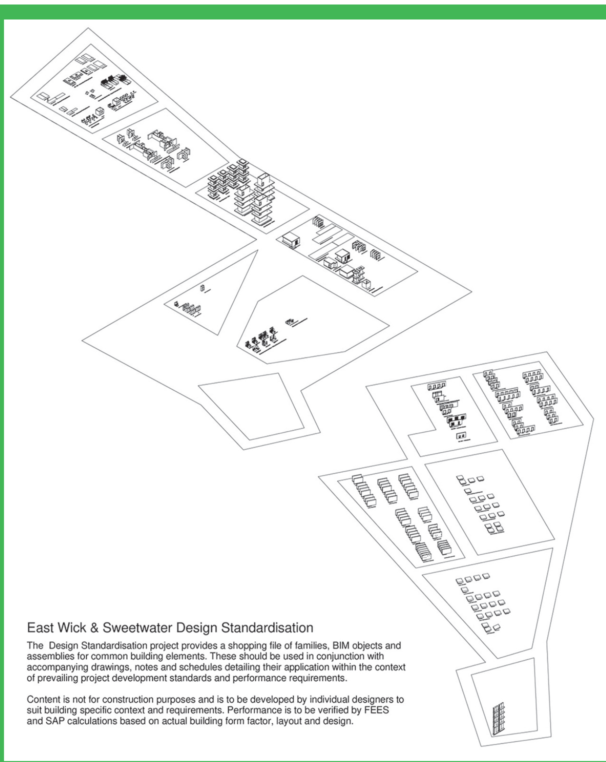


Figure 33 Design standardisation

During this engagement, the team reviewed procurement strategies covering design responsibility and contractor's design portion (CDP), sequencing of works and co-ordination with the design programme. We identified programme constraints for the sales and marketing team to make final decisions over specification prior to commencement of manufacture.

The first standardisation project in 2016

A design standardisation project was successfully led for the client creating a comprehensive pattern book and 'virtual' BIM warehouse of design solutions for common building elements and envelope. This will be applied across all seven phases and 1500 homes of this development. The project is innovative as it enables detailed design issues to be solved by a team comprising designers, engineers, constructors, specialist suppliers, cost planners and other stakeholders who will be responsible for facilities and housing management. This ensures that a costed design solution for key elements of the building, fully co-ordinated with the energy, sustainability and sales and marketing strategies, can be provided for the designers for each parcel even before the detailed planning stage scheme is developed. The solutions developed include a 'smart city' approach for combining a variety of apps and technologies already in the market into one seamless set of digital services for East Wick + Sweetwater to aid efficiency, connectivity and mobility.

Case study 10 (contd)

Figure 34 Architect's impression

A standard solution for plant and service risers and utility cupboards within dwellings was developed. Plant and riser requirements have been highly specialised incorporating the interface with the Olympic Park district heating system, and smart metering across all utilities. The utility cupboard has been developed as a component which can be prefabricated, and incorporates the district heating system heat interchange unit, hot- and cold-water services, heating manifolds, mechanical ventilation with heat recovery (MVHR) units and controls for electrical, IT and comms systems. The project team liaised closely with the designers of the site-wide utilities infrastructure as well as the district heating system provider to determine the plant room strategy and specialised design, access and maintenance requirements associated with the system. Ceiling voids in standardised floor build-ups are developed to enable inclusion of sound attenuation for MVHR systems, and space planning allows for NO2 filters to be fitted where required to meet air quality requirements. The team also ran collaborative workshops with the energy assessor and sustainability consultant to establish all requirements for building services, eg where the selection of systems such as MVHR are driven by the energy strategy meeting the Fabric Energy Efficiency Standard (FEES).

The early engagement of offsite manufacturers through two-stage procurement brings input and expertise from specific manufacturers forward, into the concept design stage. This arrangement is hugely beneficial to both the design team and the project; the collaborative relationship with the manufacturer enables a project to be designed with particular offsite systems in mind, and the need for abortive redesign work – to adjust a scheme not previously designed with MMC in mind – would be avoided. This approach brings significant programme advantages to a project.

“Two-stage tendering can work well for both employers and contractors if it is set up and controlled in a way that respects both parties’ risk appetite. Main contractors like it because, in conventional two stage, if they are successful at the first stage, they are in a stronger position to develop their overall offer, often on a negotiated basis. The benefit to employers of conventional two stage is the main contractor positively contributes to the schedule, design, buildability and logistics during the second stage, in collaboration with the employer’s team.”[(36)] Kristoffer Hudson, Turner & Townsend plc.

Potential suppliers and subcontractors should be meticulously assessed during the pre-qualification phase. Their financial resources, management, leadership and commercial controls should be interrogated to ascertain their real-time capability and capacity.

Case study 11

Beckton Sewage Treatment Works AMP7 upgrade (Thames Water Utility Ltd)

DfMA efficiency is effectively driven by the contractor as part of their design development when engaged by ICHEME Burgundy Book Conditions of Contract with Thames Water’s amendments. The level of detail and timing of co-ordination required between the manufacturing team and designer was clarified as early as possible in the programme, which promoted an alignment of principles, opportunities, and understanding of the likely constraints.

Before the contract stage Thames Water often undertake initial due diligence of potential viable solutions to ensure the principles align with their design asset standards. Typically DfMA proposals require internal governance through a waiver system to grant deviations that are regularly a pre-requisite to DfMA solution development. There are often challenges leading to wide-ranging discussions including reducing long-term serviceability, access and maintenance provisions, resilience, factors of safety etc.

The successful implementation of DfMA requires early consideration as part of the design process to create a clear concept. With early involvement of the supply chain, the Utilities Contract Regulations (UCR) allow a utility company to seek or accept advice from independent experts or authorities or from market participants before starting the procurement procedure. However, this is restricted by compliance with the regulations that competition should not distort or violate principles of non-discrimination and transparency. In respect to the client’s involvement, procurement regulations can be tricky to navigate but there is nothing in the regulations preventing a utility company from specifying such solution in compliance with the regulations. The challenge remains in developing a solution with a third party and that

Case study 11 (contd)

party being unsuccessful at contract award.

Pre-cast concrete water retaining solutions are common within the water industry. At Beckton STW the project has benefitted from the incremental development of the 2007 project solution for the construction of two 85m x 41m x 8.5m deep tanks. This has incorporated the lessons learnt from that project, which has resulted in modifying the lateral support beam tie-in arrangement, formwork for the pouring of concrete in between the twin wall was simplified, and minimising site effort by reducing the complexity at the panel connection interface points. These provided benefit in requiring less working space, plant, and labour, thereby also improving productivity.

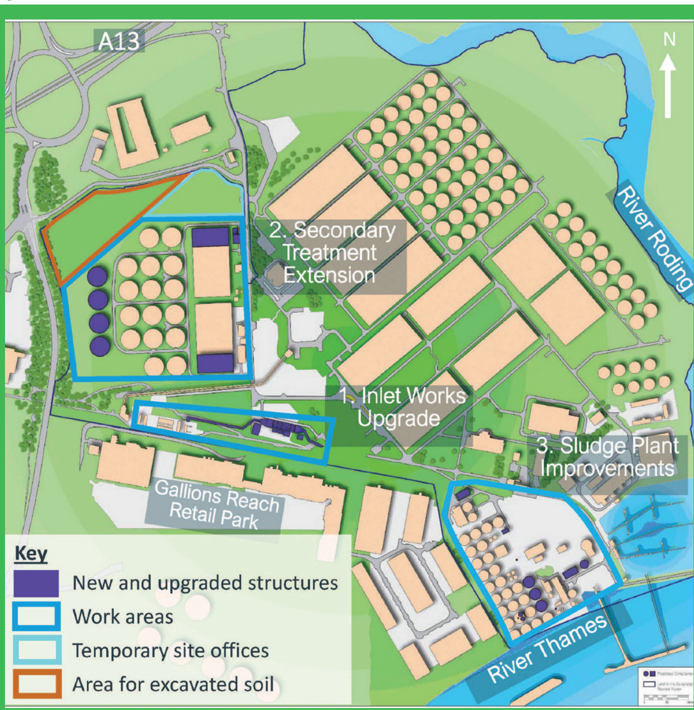


Figure 35 The areas of work include new tanks and buildings being built (purple), temporary site offices (light blue), and an area to deposit excavated soil (brown) from the work

Product control within the off-site establishment remains a key to the success. Maintaining within tight tolerances has proven to be tricky. Pour pressure on formwork can result in deviations in panel sizing that has affected some pieces of the jigsaw puzzle, resulting in re-casting or on-site remediation works including planing of the concrete surface. The placement of reinforcement for the in-situ concrete phase in tight restricted areas has created unexpected difficulties and challenges to avoid concrete segregation when panels are ‘stitched’ together. Further research is recommended to understand how density of reinforcement can be minimised to suit this technology but also complying to design standards for water retaining structures.

The implementation of plant and equipment manufactured off-site is becoming ever more popular. Handrailing installation on walkways has been developed for this project and proven to reduce the site installation period and improved safety in terms of limited working at height requirements. The lifting operations have benefitted from the site already having large lift capacity craneage and the construction logistics have enabled access into the working areas to align with the civil engineering works. Systemising pipework and cable containment onto the walkways for future projects are the next generation opportunities to be investigated.

In terms of embedded carbon for the project, the DfMA solution is considered to be carbon neutral; the same materials are used in similar quantities leading to a 5% reduction in waste.

Case study 11 (contd)

These examples emphasise the benefits of DfMA accrued at Beckton STW of improved product, reduced installation period, and the ongoing development opportunity that has made construction activity safer. The project has demonstrated how incremental innovation can be achieved on a relatively new and stable construction method.

Programme and logistics

An offsite manufacturer's fabrication lead-in times and production slots need to be fully understood and considered for the project programme to be developed. The factory location needs to be ascertained and visits arranged for the project team to review the production conditions and processes, especially quality control. Lukas Thiel states that *"MMC logistics are also different, with an emphasis on precision delivery times, with confirmed access routes and crane lift capacities. Different skill sets are required, impacting on local training and job opportunities. Longer lead-in times for MMC also put pressure on contracts, another reason why the shift in system thinking needs to start as soon as the idea to develop a site is conceived."*(37)

Offsite lead-in times can be longer than traditional construction methods, so if the offsite fabrication programme needs to begin before activities begin on site, the temporary storage of assemblies will be needed. In addition, the location, costs, timeframe and logistics of their delivery to site needs to be factored into the programme and cost plan. Thiel explains: *"First and foremost to any shift is that the use of MMC and DfMA must be rooted in system process thinking; it must also be the foremost consideration in a project's initial viability assessment."*(38)

The availability of materials needed to assemble offsite elements, through the offsite supply chains, needs to be carefully managed by the offsite manufacturer, but once secured, offsite processes offer greater certainty in terms of programme delivery due to the enclosed factory conditions; there is no risk of work not progressing due to weather conditions.

Sequencing

Offsite construction requires the entire project team to work in different ways from the traditional norm. Project processes and working methods need to be understood by all parties for an offsite scheme to be successful.

The sequencing of design is different from what many people are used to; the design of the elements that are to be manufactured offsite need to be suitably advanced at tender stage such that their manufacture can start as soon as possible after the contractor has been appointed. OSM is undertaken in tandem with the construction of the substructure onsite, so that when the groundworks are complete the offsite components can be installed immediately afterwards. The various contractors' responsibilities and scope of works of all parties should be accurately set out and understood to avoid gaps and delays, and the interfaces between packages co-ordinated. Two-stage procurement assists by enabling close and early collaboration and co-ordination between the offsite manufacturer and main contractor, who need to carefully manage the sequencing of traditional and offsite construction works. Sites that have constrained access or are within dense urban environments, for example, can provide delivery and lifting challenges for large, prefabricated assemblies if restrictions are imposed by local authorities, requiring these works to be undertaken out of hours. Deliveries of volumetric modules can require several very large lorries to visit the site within a short space of time, which can cause logistical complications, so the sequencing of the construction is co-ordinated with the manufacturer's lead time and site delivery timeframe.

Benchmarking

Crucial to the success of offsite construction is the production of benchmark elements and mock-ups, which should be factored into the overall procurement and construction programmes, These can be delivered under a PCSA or under the main contract at the beginning of RIBA Stage 5 (manufacturing and construction).

The use of mock-ups enables critical dimensions to be ratified, connections and interfaces to be tested, and quality to be reviewed and the 'gold' standard – against which all other subsequent components are assessed – to be established.

A fully co-ordinated design, signed-off by the client, is needed for fabrication of mock-ups to begin. Once production of the main contract works is underway, design changes can be difficult, costly, or impossible to achieve, so client confidence in the design, and timely approval of mock-ups is essential, especially for MMC Category 1.[39]

Testing and accreditation

In addition to defect identification and rectification, offsite construction offers opportunities for activities that are typically carried out on site, to be undertaken at the point of manufacture. Pressure-testing of first-fix services, hose testing of windows and façades, acoustic and impact testing, and trial stacking of multiple components are examples of traditionally site-based activities that can be undertaken offsite and help to reduce the construction programme.

Subject to agreement with local authority building control or the project's approved inspector, building control inspections can also be undertaken before components leave the manufacturer's facility and are transported to site. Should any remedial works be needed to achieve statutory compliance these can be undertaken by the manufacturer.

The Buildoffsite Property Assurance Scheme (BOPAS) was developed to address concerns and perceived risks associated with innovative construction technologies (see **Chapter 10**).

Specifying flexibility and inclusion of MMC

8

J-P Cartz and Ahmad Alrifai, WSP

All construction projects need written instructions that support the drawings and schedules. This will ensure the constructor fully understands the design intent and has the full detail of what is required to be procured and installed and when. These written instructions, or specifications, will include material properties such as strength and weight, but also information on how to assemble the individual parts and under what conditions. For example, works that are allowed to be carried out in sub-zero temperatures, curing of materials that are poured in situ and testing of material samples.

Example 9

Off-site delivery programme

WSP: Structural engineering, building services, acoustics

WSP has developed a modular building system, manufactured in a factory using a production line and robotics. When these units leave the production line they are fully fitted and finished as high specification modules for houses and apartments. Delivered to site and stacked to create fast-build, high quality homes from 3 to 20 storeys. The target is for 30% of Berkeley residential pipeline to be entirely built offsite using the new system approach.

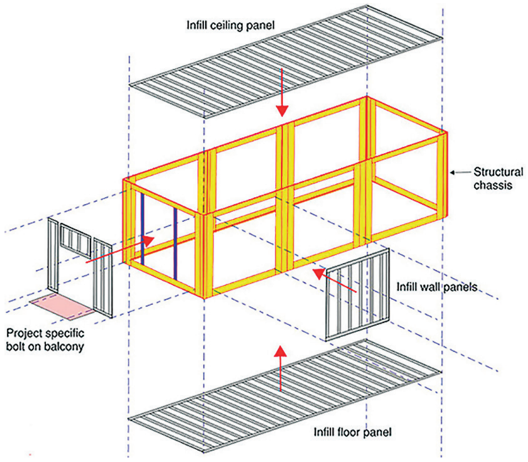


Figure 36 Modular structure and panelised sub-assemblies (courtesy WSP

Traditional specifications and procurement

For buildings, the drafting of specifications starts during RIBA Stage 2 with the definition of the outline specification. This normally includes the basic design assumptions considered at that point, such as building loads, material properties, fire requirements and corrosion protection. Traditionally, as the design drawings develop into greater details in the later design Stages 3 and 4, the outline specification is extended to include references to the appropriate national design codes, codes of practice, and standard references to materials and processes. Numerous clauses are added to the specification, generally as defined by the National Building Specification (NBS). During the process the design team has full control of the specification and details will be amended during co-ordination of the different disciplines involved in the project. This is to incorporate changes or instructions from the client or new requirements from the other design disciplines as the project definition matures. This is an iterative process with many design cycles that converge towards a bespoke design solution.

The gradual development of the more traditional specifications provides clients with greater flexibility in terms of decision making, as the details and finishes can normally be changed later in the programme. The design goes through iterations, and each iteration offers the client opportunities to change their ideas, to review and interrogate in detail all aspects and potentially to instruct the design team to change various clauses with controlled cost and programme implications; the specification is not issued to the market until the end of Stage 4. It is only at that point that the specification will be examined by various contractors and that bids will be submitted reflecting all the client requirements as set out in all the issued material. However, a disadvantage to traditional specifications, is that the market is accessed later in the design process, delaying feedback and losing the opportunity of incorporating aspects that could allow other MMC solutions that may have provided more effective solutions – in addition to a shorter delivery programme.

The challenge with MMC solutions, is that different systems will have their own specific elements for an efficient design and if not considered early in the design process, MMC solutions then become excluded from the design. This is because programme and design costs prevent other MMC proposals to be co-ordinated within the project at this late stage. The early exclusion of MMC solutions is counter-productive and does not serve best interest for the client or wider society. It can be demonstrated that MMC solutions offer faster construction programmes with less waste, addressing skills and material shortages and current complex sustainability and procurement issues.

Infrastructure clients tend to have standard specifications that are reused over multiple projects. While these might enable, but do not promote, offsite construction, they are generally not changeable to a great extent from one project to another. This is generally due to risk avoidance, and consistency in maintenance and repair are important to clients rather than unique solutions.

Performance specifications – MMC

With the traditional design process, specifications are developed in line with detail technical drawings and issued as part of a comprehensive tender package at the end of the detail design in Stage 4. The alternative would be to limit the tender package to what is termed a performance specification. This is a document that provides instructions defining the specifics of the project, such as the required final output of the works, but is left open for the market to determine the most effective means of achieving that final output. This is the purpose of the performance specification. It should be developed early in the design process and issued towards the end of the concept design in Stage 2 or early in developed design Stage 3. The document (performance specification) provides greater flexibility to the supply chain as the constructor and manufacturer would carry out the developed design in Stage 3 and the following design stages, allowing the chosen MMC products to be fully integrated into the design.

When drafting a performance specification, it is important to take great care in the completeness and accuracy of the content. Typically, there will be references to well established design codes and to the criteria to be achieved in all aspects of the project design. For example, programme, sustainability targets and programme delivery dates would be defined. To optimise the benefits of this approach, the performance specification for MMC systems, contractors need to understand all the building performance criteria, but the document should avoid prescribing the MMC solutions. The detailed design would be developed by the contractor, and subject to the best adapted MMC system.

As MMC solutions are composed of standardised units, pricing, detailing and manufacturing is highly efficient, including repeat solutions that are reconfigured, to an extent, to suit project specifics. Assemblage is offsite, under manufacturing conditions affording higher quality control and productivity and predictability of costs and material availability. This increase in productivity allows the design from Stage 3 onwards and the manufacturing and construction programmes to be significantly reduced.

In developing the performance specification, the design team should understand the relevant supply chain to allow MMC solutions to incorporate the basic requirements of those solutions. So, performance specifications are both inward and outward looking:

- inward looking in terms of the client and design code requirements
- outward looking in terms of the available MMC solutions and realistic supply chain capability and criteria.

Example 10

Courtyard by Marriott, Reykjavik, Iceland

Module provider: CIMC Modular Building Systems

WSP: Structural Engineering and Building Services

A 150 key hotel opened in 2019. This project was the first hotel of Courtyard by Marriott in the Nordic region, and also the first modular steel structure hotel project in Iceland. Due to the geographical and climatic differences in Iceland, the hotel has higher requirements for steel, fire prevention, sound insulation and lighting. The project meets both local standards and the required Marriott hotel quality standards and incorporates the local seismic design code.

Figure 37 Courtyard by Marriott (courtesy WSP)

For example, a project with mainly large spans would not necessarily be adapted to MMC solutions with volumetric modules limited in size due to transport restrictions. A performance specification targeting the appropriate supply chain capabilities will provide the more efficient construction solutions and shorter overall design and construction programmes.

Flexibility and risk management

Procurement risks, in times of stability and greater predictability of supply chains are normally manageable and relatively low. However, in times of increased volatility, labour and material shortages and transport disorders this aspect of traditional specifications and traditional procurement routes increase procurement risk and may result in delays due to procurement of materials, specialist labour or equipment that may be required but in short supply, or in securing manufacturing or shipping slots. This is because the traditional procurement process has less opportunity for the market to inform the design compared with a performance specification, as the documents are issued to the market as a tender at the end of Stage 4, when the design is already largely complete and any changes to that design, other than limited variations, would result in significant abortive work and costs and delays due to design change.

In contrast, performance specifications offer the benefit of being issued sooner to the market as the focus of the performance specification is on the end product, and not the creation of an entirely prescriptive description of required manufacturing or construction processes that result in an entirely bespoke solution. This early access provides the market with the flexibility to adapt various solutions for the optimal outcome, immediately incorporating the specifics of the supply chain.

There can be a perceived loss of flexibility from the client's perspective, but the earlier feedback from the market can offer a different form of flexibility, such as the potential to change materials, form and opportunities of a shorter construction programme. Most importantly, performance specifications allow the details of procurement to influence significant design decisions. For example, early feedback from the market would allow the various requirements from different MMC solutions to be incorporated into the design, which otherwise would only be possible with abortive work and delay.

Indeed, the specific requirements of different standardised construction systems normally cannot be accommodated into the design if not considered in the early design stages. Features like maximised repetition, floor and ceiling depths, overall building heights etc would have significant impact on the spatial setting out of projects and it would normally be considered unpractical to modify the design to that extent after developed design Stage 3. If Category 0 preconditions are not achieved at the start of the project, this typically leads to lost opportunities in the development of alternative solutions and, in particular, with MMC projects. It could be argued that performance specifications increase client flexibility, as it offers them a wider variety of construction solutions. The client then has the option of proceeding with the design team bespoke design solution or to incorporate MMC alternatives proposed by specialist contractors with cost and programme benefits.

Under current global conditions of a post-pandemic world, international conflict, disruption to shipping routes and the energy crisis, project procurement is higher risk with increased volatility of prices and availability of materials and goods. Under such conditions, earlier access to the supply chain will tend to reduce these risks as critical slot times can be incorporated into the design programme and critical shortages identified earlier in the design process can be better managed. These matters may appear highly conjectural; however, material and skill shortages and sustainability issues are realistic for mid to long-term trends.

Performance specification content and tender returns

Performance specifications enable the use of MMC, and the benefits associated with MMC as set out in **Chapter 2.** The specification needs to be sufficiently detailed to enable the specialist contractors to fully understand how their products could be best integrated into the overall design. Simple reference to design codes would not be enough.

Items to include in the performance specification are:

- ultimate resistance
- stability and structural integrity
- occupancy type for all areas
- allowable lateral sway – serviceability performance
- dynamic performance (ie floors)
- cladding and thermal performance
- fire resistance
- acoustic performance
- durability
- balcony and façade attachments
- movement joint positions and other project bespoke requirements
- environmental performance and contributions to achieving net-zero carbon (embodied and in use).

Infrastructure projects often have a design life of 120 years, and the assets have multiple maintenance contractors over that time (sometimes as many as 24) all of whom could be responsible for any faults or failures. Consistency of maintenance requirements is also important with potentially specialist maintenance needs and specially trained staff. This can be challenging for an infrastructure operator of a rail or road network who would need to provide emergency and planned maintenance and repair to thousands of miles of infrastructure on a contracted basis. There is an opportunity to define these requirements within the performance specification and to refine the maintenance strategy with the supply chain. This needs to be communicated to future asset/facilities management service providers, especially in view of the growing requirement to incorporate sensing and control systems (IoT) into assets.

Generally, local planning authority requirements do not apply to national infrastructure projects built under a development consent order. However, there may be a need to allow for specifying finishes to the modular products to allow for local planning authority requirements.

Building roof live loads, in particular, need to be well defined, as there exists critical and large variations between maintenance-only access loads, public access, or plant loads.

MMC solutions involving modules with International Organization for Standardization (ISO) container dimensions[86, 87] and connection details can be moved via the existing international freight container transport systems. For overseas transport this could be conditional to the MMC system being viable. The unit dimensions could be varied in accordance with national road clearance dimensional standards and the type of vehicle used.

Lifting – from a single point, with cross beams, secondary frames, or pairs of cross beams – generally will be defined by the specialist contractor however any restrictions need to be included in the tender and understanding the installation process will be required to ensure the system is compatible with the site configuration and arrangements. The erection sequence should form part of the specialist contractor tender return.

Contractually the building loads should be derived by the design team and included in the specification to avoid differences in interpretation and inconsistencies, for example in the cost comparison exercises carried out by the quantity surveyor at tender return. All tender returns should be based on the same basics such as geometrical, loading, durability and environmental requirements.

The joints between the MMC items and traditional construction will also need to demonstrate adequate strength and durability – in accordance with the design team performance specification – and that methodologies have been considered to ensure the structure remains robust during its working life. Adequate performance criteria should be provided by the design team to make such assessments. Connections should also be reviewed for robustness clauses such as disproportionate collapse code requirements.

Design liabilities

Adopting several MMC different solutions in the same project may lead to significant portions of the building or infrastructure project being designed by different parties.

Ownership of the design liabilities by different design organisations, on behalf of the client, will be required. Professional liability will need to be defined and the design team needs to recognise which risks will be best placed with them and which will need to be shared with the client and/or contractor. Typically, the manufacturers and builders would be responsible for their specific outputs, but the liability of the project as a whole should remain with the design team, who would normally be responsible for assembling the different MMC technologies into a single and coherent project. The design team needs to recognise that tender periods are typically shorter than the initial design stages and the performance specification should be prescriptive in terms of loads, load combinations and interpretation of the design clauses, for example, disproportionate collapse, interfaces between packages, and allowable movement between different packages.

The design team should typically retain the overall design responsibility; a construction project could contain several types of MMC or may include an element of traditional construction such as the foundations, drainage and connection to the local networks or the stability shear cores. The design team would be responsible for considering the overall stability of the structure, integrating the various parts of the building, and monitoring planning conditions and the various planning submissions It is the requirement to satisfy all such items that need to be set out clearly in the performance specification. The specialist contractors would be responsible for the delivery of their own specific products, but it would be unrealistic to assume that a specialist precast flooring contractor could become liable for an entire building without becoming involved in the design until the tender stage. Duties are shared between the different parties, so careful definition and co-ordination of the roles and responsibilities is needed; the performance specification should include all inputs and outputs and limits of liability. The MMC provider typically remains liable for the design of the particular constituent parts that form the package.

There may be alternative solutions presented by MMC providers that would bring changes to the performance specification. It is the provider's responsibility to highlight and co-ordinate those changes with the design team who would then review the proposal and either reject the bid as non-compliant or accept it with modifications to the performance specification. They will then re-issue it as a controlled document, with changes incorporated.

Programme

As has been suggested, a typical key benefit of offsite MMC is speed of construction compared to traditional methods. Generally, design and construction programmes can be reduced by around 50% compared to traditional programmes. This means that the performance specification will need sufficient information to allow the specialist contractors to develop their detailed design and tender return within the allocated programme slot. For programme benefits to materialise, detailed design and manufacturing of the offsite units will have to start on a date which incorporates the site delivery dates. This would also need to be co-ordinated with the completion of the supporting structure or required infrastructure. Lead-in time for potential prototypes and design and manufacture of the MMC items needs to be fully considered when developing the programme and shortlisting the specialist contractors.

As the programme evolves at a faster pace than traditional construction, it is vital to convey to all parties that approvals also evolve quicker. Once the manufacturing process has started, any design change becomes onerous and there is the potential to lose the programme benefits that would otherwise materialise. This can be a risk as client teams traditionally are accustomed to working on longer design programmes that allow, in many circumstances, later changes to certain detail (eg finishes). Client teams may find the shortened approvals period challenging. As MMC solutions often incorporate finishes, these will need to be procured in accordance with the manufacturing programme, which will be much sooner than a conventional construction programme.

The start of large construction projects traditionally offer photo opportunities for officials and politicians. In some instances the traditional ground-breaking might need to be replaced with a factory visit and walk about. Perhaps this would be an opportunity to highlight the ongoing changes in the construction industry.

Sustainability

Climate change is increasingly at the forefront of client perception, and legislation is evolving rapidly to enhance building performances and to reduce embodied carbon and whole life cycle costs. MMC solutions combined with an earlier access to the supply chain through performance specifications can offer holistic and fully documented solutions to these aspects of construction. This may not otherwise be fully understood as being directly linked to supply chains and procurement. For example, an item such as the location of a factory in the supply chain, could be a major influence which may not have been determined by design methods alone. Supply chains and procurement will increasingly influence MMC solutions.

In the current climate emergency, standard systems produced offsite from factories and assembled on site offer more sustainable solutions. The carbon content can be more accurately assessed with a standard product from a production line compared to bespoke items. Key criteria corresponding to client preferences from a more general environmental, social and governance (ESG) point of view can be incorporated into the performance specification and the less suitable supply chains and related construction materials or methods ruled out based on those specific requirements. As this process of filtering the market would occur at the start of the design programme, ESG has better opportunities of directly informing the end product.

The development of specific MMC solutions for a given project is also a possible outcome, however the supply chain will require assurance of return on investment should new manufacturing plants be required to deliver on the DfMA philosophy. Also, teams of installers will need training and certification. Such solutions may be viable for larger projects with longer construction programmes, but more generally pre-existing solutions will offer more efficient solutions. In the first instance, the design team should review current supply chain capabilities before resorting to project-based MMC development programmes.

Perceived advantages of performance specifications will continue to grow in importance in a world of new and increased energy and climate challenges. Traditional specifications could deal with the challenges mentioned, but with significantly greater risks of abortive work, increased costs and delay.

Product trends in different sectors

Offsite construction (prefabrication)

This is a growing trend in the construction industry. The approach entails the procurement, manufacturing and assembly of project components in a temporary controlled environment before being shipped and installed permanently on site. Many of the MMC categories discussed fall under offsite construction where a modular approach is used to manufacture identical developments.

The ability to pre-manufacture building components could provide several advantages to the project. These are covered in **Chapter 2**.

- **Infrastructure bridges and viaducts and utilities.** These structures are huge investments so they need to be of a consistently high quality to accommodate an increasing number of requirements and shorter construction programme times. They should also have minimal disruption during construction and maintenance.

  Transport systems are more energy efficient when slopes and level changes are minimised to provide a flatter trajectory and alignment. MMC can be developed to refine this through the early integration in the design of alignment systems and positioning aids.

  Increasingly, these structures are becoming multi-functional, integrating transport, a route for communications and control systems, and services provision (power, water and drainage) incorporating mitigation measures such as acoustic and wind barriers. Integrating different materials and processes is easier in a controlled factory environment (eg where dimensional tolerances are easier to achieve consistently).

  The aesthetic of bridges and viaducts should be appealing and sympathetic to the environment by minimising the perceived visual impact with less intrusive lighting systems and higher quality finishes. MMC allows works to be completed with tighter quality control and to a higher standard due to the controlled offsite production processes. These conditions also reduce material content by using lighter weight designs.

Almost all of a structure can now be produced off site. The scale of a project or programme may make it possible for specialist manufacturers to invest in MMC design solutions. A key factor will be early engagement with the supply chain. This is to allow enough flexibility in the design for the supply chain to be able to contribute with solutions adapted to their works and existing database of components. For smaller scale projects, the design team will need to understand the supply chain cost drivers and existing capabilities, as further capital investment may not be realistic. Some large and long components may be transported by road, but site logistics and temporary factories will be major considerations.

If the MMC solution adopted requires more offsite components and joints, it is recognised that greater corrosion risks will exist if the joints are not adequately protected. While sealing joints is feasible, for greater durability, protection of vulnerable joints should be considered as part of the bridge or viaduct's structural health care management system. The use of corrosion monitoring and impressed current cathodic protection should be considered. These can be incorporated during the manufacturing process and combined with a digital twin for the maintenance programme.

- **The IoT.** This is being exploited through new construction systems:

  Digital twins of construction projects – buildings and infrastructure – combined with sensors embedded within the structures, measuring temperature, loads, stresses and corrosion, will offer valuable data to gain knowledge about the structural and operational performance through monitoring data. Signals could be determined as trigger points for key maintenance operations.

  Cambridge University's civil engineering department have used sensing systems inside a test building including:

  - fibre optic sensing
  - fibre Bragg grating
  - distributed strain sensing
  - distributed temperature sensing

  Systems could also be incorporated for monitoring the corrosion or the carbonation of structures as well as the performance of multi-functional services infrastructure (transport, communications, security, power, water and drainage) and these could be linked through digital twins into networks and integrated into the IoT.

  Adopting corrosion protection measures such as galvanic cathodic protection (GCP) or impressed current cathodic protection (ICCP) – and structural monitoring systems as referred to in Chapter 6 and enabling remotely accessed databases of general or particular performance of an asset without disruption to its use, may be of benefit for all large projects. The benefits of non-disruptive performance monitoring is illustrated in the catastrophic failure of the Morandi Bridge in Genoa, Italy in 2018.[88] The offsite production of precast concrete offers ideal conditions to integrate monitoring technology inside the structural elements. The resulting databases with accessible reporting offer stakeholders vastly improved clarity of condition, safety, asset value and the timely programming of maintenance works.

Due to the energy and carbon intensity of the manufacture of zinc and its limited, finite life expectancy, ICCP systems are increasingly being installed. Factory-moulded cementitious ICCP MAUs can be connected directly to the reinforcement and interconnected with the corrosion management system. Further details of these systems are presented in Achieving sustainable resilience in new precast concrete structures.[30] This detail could be included in the performance specification along with the required testing regime to be conducted before delivery to site.

Monitoring structures could feed a database incorporating overall structural behaviour and maintenance needs but also could be used for recording real time levels of performance for acoustics, thermal properties and accelerations due to wind or seismic activity and vibrations. The data could be linked to the emergency services in case of extreme events. It could also be incorporated into product development and into future design codes. Intelligent selection and validation of services for communities (heating, cooling, drainage, water supply etc) could be managed through the extension of such systems to maximise the use of existing infrastructure. Combined with systems of energy storage, these solutions could be significant contributors to achieving net zero buildings and net zero communities.

Advanced building materials

The increased pressure on innovation and sustainability in the construction industry has resulted in organisations and institutions focusing more on the R&D of new advanced building materials (ABM). Such materials range from providing alternative solutions to traditional construction products to modifying existing ones which result in enhanced properties that are more sustainable, efficient and durable.

ABMs have two key characteristics:

1 **Performance.** ABMs offer exceptional performance which improve the functionality of buildings and create healthier living spaces for occupants. They may also help reduce environmental impacts associated with conventional building systems.

2 **Materials innovation.** Advances in material science have enabled the development of new formulations and combinations of materials that provide enhanced performance capabilities beyond those available from traditional building systems alone.

A prime example of an ABM is mass timber. It is one of the most recent innovations in this field, and can be used as an alternative to concrete and steel. Mass timber uses state-of-the-art manufacturing technologies to glue, dowel or nail standard sawn timber boards together in layers. This is a more efficient method than conventional timber framing and results in a stronger building.

Mass timber structures are typically made from CLT, glued laminated timber (GLT) or LVL. CLT is formed by gluing together multiple layers of wood veneers into a single board that can be up to 12m long. GLT is similar to CLT, but instead of using veneer, it uses solid lumber boards that are glued together. LVL is produced by gluing together two or more layers of dimensional lumber.

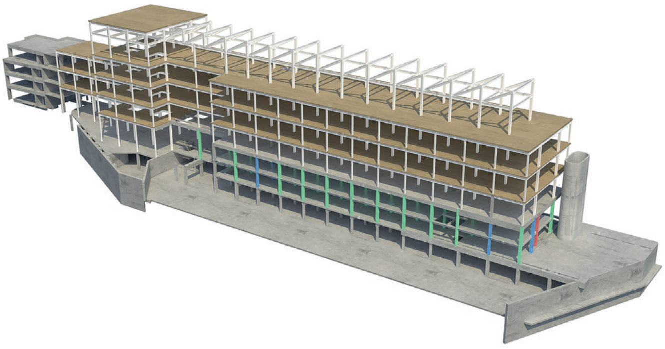


Figure 38 CLT slabs at Grand Union House, London (courtesy WSP)

ABMs also comprise **low-carbon concrete**:

- MMC includes the offsite production of the precast concrete sector. Factory-controlled conditions for precast concrete generally offers better quality control and finishes (see *Offsite construction*). The availability and ability to develop performance-based specifications for offsite products provides a means of introducing new materials. This is particularly relevant for low-carbon precast concretes, such as AACMs, for which there is a BSI published, publicly available specification, PAS 8820:2016.(40) AACMs provide an efficient route for using low-carbon materials such as ground granulated blast-furnace slag (GGBS) and pulverised fuel ash (PFA).
- The Low Carbon Concrete Routemap(31) recommends:
  - **Action 1:** Cross-industry efforts to standardise measuring, reporting and benchmarking of the GHGs associated with different types of concrete.
  - **Action 2:** A co-ordinated approach between the client, industry and government to optimise the benefits of concrete for carbon. Embedding the requirement to address CO_2e within the whole supply chain.
  - **Action 3:** Concrete industry to promote the use of best practices and new technologies in concrete mix design, batching and production to realise consistent and lower carbon concrete. Government support will accelerate this process.

  The approach described in Actions 1 and 2 are consistent with the processes identified under the section Performance specification content and tender returns. Again, the supply chain needs to be involved early in the process before it is too late to embed the requirements to address low-carbon concrete issues and achieving the client objectives in the design, ie sustainability targets and optimising the embodied carbon.

The embodied carbon is the total GHG emissions and removals associated with materials and construction processes throughout the whole life cycle, including disposal (modules A1-A5,B1-B5, C1-C4 according to BS EN 15978:2011[23]). These are also issues that cannot be considered completely by the design team working in isolation.

Action 3 involves specifying adequate materials to improve the low-carbon properties of concrete and carbon sequestration. The Low Carbon Concrete Routemap[31] refers to GGBS, FA/PFA, limestone and AACMs.

GGBS is a secondary cementitious material (SCM) and is mainly used in concrete as a Portland cement replacement to reduce permeability and improve durability. It is a by-product from the blast furnaces used to make iron.

SCM are cement constituents other than Portland cement clinker as defined in Clause 5.2 of BS EN 197-1.[41] SCMs may be produced from naturally occurring materials with minimal processing or may arise from wastes or by-products from other industries.

Fly ash/pulverised fuel ash (FA/PFA), another SCM, is the fine ash collected from the flue gases of mainly coal-fired furnaces during the combustion process. Fly ash can also mean ash from furnaces other than coal-fired power station furnaces. In FA/PFA for concrete see BS EN 450-1:2018.[42] (Note that municipal and industrial waste incineration ashes do not conform to this standard.)

AACM are materials that gain strength by means of a chemical reaction between a source of alkali and an aluminate-rich material, eg GGBS, fly ash or natural pozzolans such as calcined clay.

Highways are now specified using general concretes (GEN) that incorporate GGBS alongside standardised prescribed concrete (ST), with a preference to GGBS where possible, based on availability and cost. However, while GGBS concrete is not made available throughout the UK, GGBS as a material is available and is being imported for use in AACMs from lower cost markets. The closure of coal-fired blast furnaces in the UK will ultimately lead to a run-down of available stocks. While medium/long-distance transportation reduces the carbon benefit, transport currently represents about 1% of the CO_2e of a M3 of concrete[89] and bulk sea freight of raw materials adds relatively little per tonne. As energy and other factors increase the cost of high carbon concrete, alternative formulations will be used more often in the offsite sector. Initial applications are likely to be where the new materials offer performance advantages, such as enhanced fire resistance and use in aggressive ground conditions.

Carbon sequestration is the storage of carbon in a place (ie a sink) where it will remain. Types of sequestration include ‘geological’, where CO_2 is captured and buried underground, and ‘biological’, where CO_2 is absorbed during the growth of plants and trees. The carbonation of concrete is also sequestration, as is the production of concrete using CO_2.

The client had high targets for sustainability, comfort and occupant well-being. 22 Bishopsgate is the largest project by floor area in the UK to be registered for WELL certification, and it has also been designed to achieve a BREEAM Excellent rating. All of the mixes contain between 20% and 40% GGBS cement replacement product, which enhances the durability of the concrete while adding to its sustainability credentials.

Figure 39 22 Bishopsgate, London (courtesy WSP)

When the Pinnacle project was abandoned in 2009 and replaced with the 22 Bishopsgate project, an innovative approach has reduced the building's embodied carbon emissions by 70%. The Pinnacle had a three-storey basement with nine floors of concrete core and piles embedded more than 50m into the ground Rather than excavating this 'stump' and beginning again, the 22 Bishopsgate project team reused 100% of the existing foundations and 50% of the basement in a design that also made use of older existing buildings on the site to create 30% more lettable area than The Pinnacle.

Lightweight steel frames

Generally, lightweight steel frames have emerged as a form of MMC, due to the following benefits:

- Speed of construction leading to potential cost savings by:
  - reduction in site preliminaries
  - reduction in plant costs
  - earlier return on capital expenditure
  - shorter borrowing period required by the developer.

- Lighter weight structures, leading to further savings in foundation design and supporting structures, and in transport and erection costs.
- Quality of construction due to the extent of offsite activities. This leads to further advantages, such as early completions, fewer snags and minimal re-work, which further increases construction speed.

Other benefits include:

- The risk and consequences of fire during construction are extremely low as steel is non-combustible and does not add to the fire load of the building.
- High levels of acoustic performance are achieved by using double skin separating walls with multiple layers of board.
- Lower U-values can be achieved cost effectively by lightweight construction without leading to excessively thick walls and loss of usable floor area.
- Cladding can be supported from light steel frames with an uninterrupted height of more than five storeys. There is no requirement in either BS 5628:2005[43] or in BS EN 1996-1-1:2005[44] for cladding to be supported by the structural frame at specific intervals. However, the junction details and ties would need to make specific allowance for the predicted relative movements.

Reduced carbon steel production and reusability of structural steel

Sensors embedded within buildings combined with a robust data management and real time visualisation software, have been installed in various research projects led by the University of Cambridge's civil engineering division. The complete monitoring package, using fibre optic sensors, is an example of how modern instrumentation technology can be developed and combined with advanced software to assess the performance of the built environment. This information is useful both for managing the monitored asset as well as to advance engineering knowledge and feedback into the design codes. Considered in parallel with the digital twin, building fatigue and the whole life cycle can be better determined and over time result in more effective structural analysis and design increasing overall material efficiency.

Parametric design and optimisation

The evolution of complex systems in the construction industry led to significantly time consuming and costly design processes which rely on considerable human and material resources. Given the numerous solutions applicable for a certain problem, design procedures are typically implemented regardless of determining the most optimum one.

The scarcity of material resources and demand for sustainable structures nowadays resulted in industries becoming more sensitive to providing more conventional solutions. The design of an efficient and cost-effective solution, without compromising the integrity of the structure, is a challenge for engineers and architects in the construction industry.

However, the advancement in high speed computational and numerical software has paved the way for the ever-growing demand for lightweight and economical structures. Engineers and architects have become capable to quickly analyse several alternative solutions using parametric design.

Parametric design is a process where a digital model is created using predefined design variables and parameters which form the relationship between various elements in the structure. Instead of manually updating the model, it can be controlled using these parameters which, through a series of algorithms, create the logic for the structure. For example, design parameters could be set to allow the height of the structure to be amended within predefined constraints. As the height changes, the rest of the structure, including walls and columns, would automatically adjust to the new height without having to manually update each one individually.

Combined with optimisation techniques, parametric design not only allow quick adjustments to the structure but also helps attain the best solution for that configuration. The search for an optimum configuration is often considered at the early concept design stages where the solution obtained either maximises or minimises the objective set. The objective function here refers to the main goal to be achieved through the analysis (ie low displacement, minimum steel tonnage). Traditionally, designs have been carried out through iterative processes until an adequate solution which satisfies the issue is obtained. However, until a suitable design is found, it is time consuming to determine through conventional analysis whether it is 'optimum'. Optimisation techniques were developed and adopted in the industry to provide certainty with regards to instantly achieving optimal designs for the same issue.'Rule-based design' comprises a database of different product capabilities to maximise repetition and reuse of standardised components.

Example 11

The Grange University Hospital, Cwmbran, Wales

Client: Aneurin Bevan University Health Board/Laing O'Rourke

WSP: structural engineering

Aneurin Bevan University Health Board is reconfiguring healthcare provision as part of 'Design for Life' Building for Wales. This centre will provide 434 beds in the largest all single room ward occupancy in Wales and will change the approach to Critical Care. The Hospital opened its wards to aid the COVID response at ABUHB and opened in September 2020, a year earlier than planned. The unique concrete 'biscuit' slab and delta beam floor system will maintain the fat slab principle which benefits service distribution and the ease of constructing walls and partitions. It also maximises the use of precast elements built off-site that will reduce the need for high levels of labour on-site. The health and safety benefits this approach provides are as important as the saving in construction time.

Figure 40 The Grange University Hospital, Cwmbran, Wales (courtesy Laing O'Rourke and WSP)

Platform-based design

This is a ‘macro’ focus approach which concentrates improving productivity and sustainability of the final product or service through adopting a programme delivery approach instead of a project delivery approach. By working beyond specific defined outputs, timescales and budgets, a platform-based approach fundamentally re-adapts the project team and integrates manufacturer-led methods and reusable products/processes to deliver strategic outcomes, and scaling the benefits beyond a single project.

Platform approaches are led by the supply chain, thereby establishing procurement routes during the early stages of a project. Through ongoing engagement between the design team and the supply chain, OSM components are developed over time to help achieve sustainability and productivity targets. So, a platform could be used as a configurator of standardised manufacturer components, which incorporates the design constraints from which a bespoke solution could be generated.

The core strategy behind platforms is to achieve economies of scale and scope by using mass-manufacturing techniques and standardisation to drive down costs. In practice, this means that companies will invest in developing a single platform that can be used across multiple products or services. It also means that they can reduce their costs by reusing the same parts across different products and services made from it.

In a platform approach, past designs can be measured, analysed and refined to create a database. The good solutions identified are associated to the relevant bank of requirements and captured in the platform – a set of digitally-designed components across multiple types of built assets. A major challenge for the construction industry is how to achieve standardisation when both client and public expectation is for variety and originality. Early engagement with the supply chain could help explore the concept solutions and assess their feasibility.

In practice, most experienced designers use and reuse their own experience (digital assets) in design to accelerate the design process (enhance the design workflows), within and across multiple projects. Standard systems are associated to design standards and code requirements and the designer should apply those components where possible, minimising the need for bespoke ones. By doing so, the experience from design and production is gradually refined and captured for future use.

It is understood that a degree of customisation may be required for the components due to specific site constraints. However, these variations are limited and are driven by the supply chain through a set of predefined variables, similar to approach implemented in parametric designs. These variables outline the capability of customisation and the extent of modifications that could be carried by the supplier to any component. The function/platform maps the optimum solutions through automated design iterations with looped verifications. Such verifications apply to the platform (past designs), the functional description (variables) and to the mapping itself. The synthesis of this process provides the output.

National Highways have a *Road to good design* guide[45] which aims to address the balance between consistency in appearance for road user safety and maintenance with the need for creating a sense of place reflective of the area. It is also developing a project that will release all design requirements and specifications into a machine-readable format that can be accessed and read by design, estimating and digital compliance software. This gives greater consistency and openness as well as quicker approvals for 'departures' from these standards. It will also assist platform-based approach for infrastructure.

The specifications are currently in production phase before release by March 2025, however, previous developments include:

- **D-COM.** Digitisation of requirements, regulations and compliance checking processes in the built environment. Final report.[46]
- A sophisticated and extendable data platform for National Highways.[47]
- **DMRB.** Latest insights from Highways England, webinar.[48]

A similar research project concentrating on the building sector has been undertaken by the D-COM network funded by the Chartered Institute of Housing with a final report due imminently. An interim briefing note The Digital compliance ecosystem[49] is available to download as well as an Open Regulation Platform (ORP)[50]

The construction industry has not yet widely exploited the opportunities offered by digitalisation and the adoption of product platforms, which could boost the efficiency of design and construction workflows. MMC generally comprises standardised components and construction details, so these processes are well suited to platform-based design.

Virtual construction

The use of virtual environments to engineer and visualise the construction of structures before they are actually built in the physical world has been around for more than a decade, but it has become more prevalent with advances in technology such as cloud computing and graphics processing unit (GPU) processing power. It is only recently that architects have been able to create models that are realistic enough to be examined by engineers, clients and contractors.

Virtual reality (VR) allows architects to walk through their designs from any angle, giving them a better understanding of their structure's aesthetics and its ability to meet functional requirements. They can also test how changes in the design affect energy use or traffic flow – before breaking ground on the project.

VR has been used in a variety of industries, from architecture and construction to the automotive industry. The benefits of VR are that it can speed up the design process by allowing users to experiment with different designs quickly, without having to worry about costs or logistics. It allows for better collaboration between multiple parties on a project who may not be in the same location.

Digital twins

A digital twin is a virtual model that represents an existing or future physical asset, for example, a building or a bridge. It can be used for many applications, such as for maintenance planning, energy efficiency analysis and predictive maintenance. The digital twin is dynamic and is continuously updated with information about the real world. The information can be obtained from sensors attached to the physical asset or from other sources, such as weather data or information from third parties.

A digital twin could be used by designers to quickly evaluate different design options during early design stages for a project. For example, they can be used to text how different materials will perform in extreme conditions such as high temperatures, strong winds and heavy rain. This allows designers to select only the materials that will perform best and avoid unnecessary physical materials testing during later stages of a project where costs are higher.

Digital twins could also be deployed to help in planning large-scale projects like infrastructure schemes where it would be difficult to predict how the traffic will flow through an area once the project is complete. Designers can carry out such assessments more accurately and run simulations to identify any bottle necks in the design before breaking ground on the project.

Digital twins offer several benefits to the construction industry:

1. **Cheaper than building a physical model.** Digital twins can be used to create virtual prototypes before construction. This allows designers to test different aspects of the design before constructing them in real life, saving time and money by eliminating unnecessary materials and preventing issues that may arise during construction.
2. **Allows testing for safety.** Identified risks on a project can be simulated using a digital twin to accurately estimate the severity and help integrate remediation strategies to make the structure safer. This makes digital twins ideal for testing for fires, earthquakes, floods and natural disasters.

The use of inter-operable digital twins is considered in more detail in **Chapter 12**.

The rapid adoption of BIM over the last decade has seen a significant change in the design approach and processes, with the ability to develop more detailed and accurate virtual information for a project quicker and earlier in the programme. Kevin Fielding, Head of BIM at Sheppard Robson, notes the following core advantages of BIM that can be applied for projects:

- digital componentisation of systems – improved quality of digital delivery and handover information
- rapid design development through kits of parts modelling
- consistent standards of delivery, client define requirements and goals, planned and executed in a consistent manner

- delivered straight to manufacturer
- efficient scheduling and planning
- improved co-ordination
- capturing asset information for transfer into asset management platforms
- supporting digital twin integration
- improved stakeholder engagement – design visualisation.

The use of OSM within projects is better aligned with a BIM-orientated design process. More accurate and detailed information is available sooner, the actual offsite components can be mirrored digitally within the BIM model and thus it facilitates improved sharing of information across industry.

Example 12

Alder Hey Children's Hospital, Liverpool, UK

Client: The Acorn Consortium including Laing O'Rourke

WSP: structural engineering, civil engineering, geotechnical engineering, transport advice, acoustics

The new hospital provides 16 operating theatres (four for day cases and 12 for inpatients) and 270 beds. The latter includes 48 critical care beds for patients in ICU, HDU and Burns, and six standard wards, each with two four bed bays and 24 single rooms and a 1200 space multi-storey car park. Responding to client Laing O'Rourke's brief to reduce on site labour, maximise off-site construction and improve health and safety generally, the vast majority of structural components, including the load-bearing sandwich panel façade, were designed to be manufactured efficiently off site.

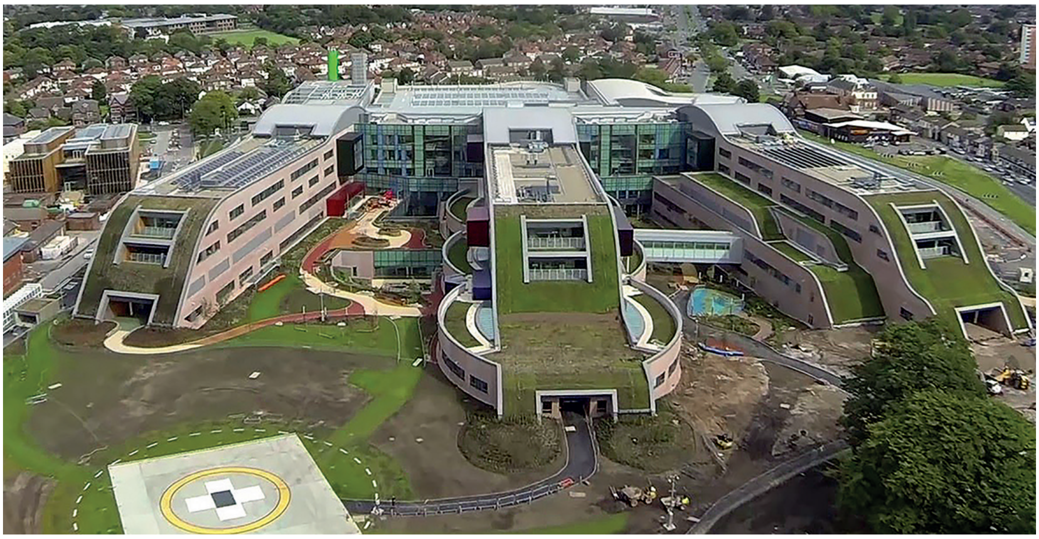


Figure 41 Alder Hey Children's Hospital (courtesy WSP)

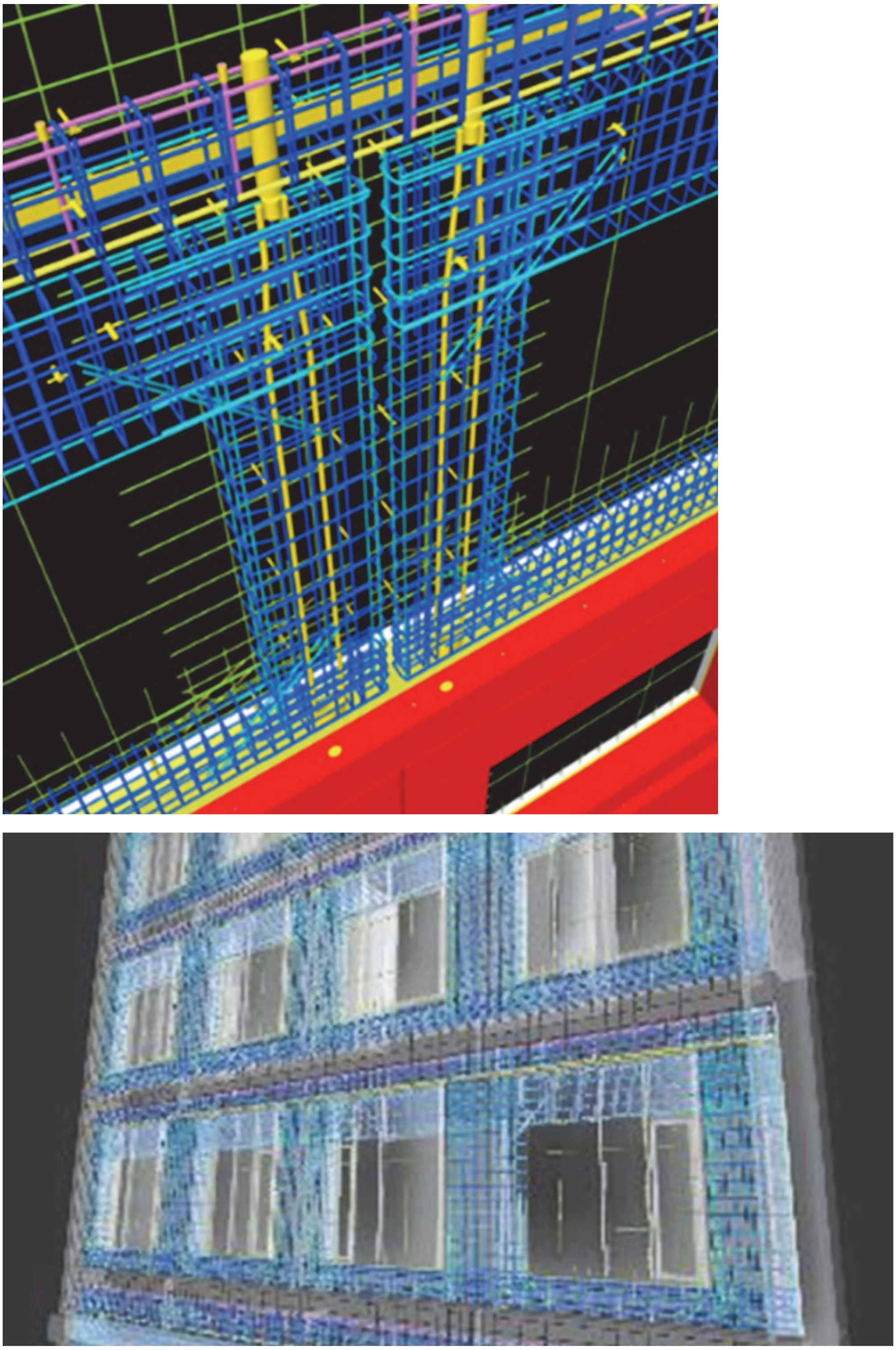


Figure 42 Collaborative model of Grange University Hospital (courtesy Laing O'Rourke and WSP)

Collaborative innovation and IP considerations

9

It is clear that the construction sector needs to innovate like never before. Buildings emit a large proportion of atmospheric CO_2, and the carbon footprint of core structural materials can be very high. Productivity has remained stubbornly low, and clients' perception of value is becoming more nuanced. Companies face rising costs, particularly for energy and related transport expenses. These, in addition to the natural evolution of markets, are driving the need for innovation, the creation of new IP.

A key barrier to innovation in construction has been the perceived or explicit requirement for designers to develop designs that can be taken to the open market for competitive tendering. In major UK public sector projects *"there is a requirement to carry out market health and capability assessments – healthy, competitive markets matter because they support our ability to achieve value for money for taxpayers."*(1) In this context it may seem challenging to specify projects in a way which facilitates the use of new products or technologies that may only be sourced from one supplier.

"Good market management is about looking beyond individual contracts and suppliers. It is about designing commercial strategies and contracts that promote healthy markets over the short, medium and long term" … "These assessments should then be used to:

- *identify potential opportunities and limitations in the market*
- *take advantage of effective new technologies and innovation*
- *consider what actions would increase competition and improve market health, including strengthening skills and capability."*(1)

A wider market strategy should be developed for assessing these points.

Further barriers to innovation, for example, include:

- The project-based nature of the sector – once a project is approved there is seldom time (or budget) to develop new products or methods within it.
- The relatively small profit margins within the larger companies (major contractors) compared to highly innovative industrial sectors.
- Much of the innovation that does happen originates with individuals, universities or within SMEs. They rarely have the resources to fully develop, test, market and produce their innovations at scale.
- The required knowledge, skills and technology may not reside with one person or company.
- Inventors typically do not want to lose control of their inventions before they can realise significant value from them.

For all of these reasons, it is often necessary to form collaborative organisations to enable innovations to be successfully developed and implemented, and agreeing from the outset who owns what background IP and how any new (foreground) IP will be owned, used and valued. Different stakeholders will have different perspectives. It is advisable to get clear agreement on this before the inventive process starts.

Nigel Fraser, Buildoffsite

The EPSRC has developed guidance on how such collaborations may be organised and has published the University and business collaboration agreements: Lambert Toolkit.[51] It consists of:

- a decision guide
- seven model research collaboration (one to one) agreements (1–6)
- four consortium (multi-party) agreements (A–D)
- heads of terms and variation agreements for both collaboration and consortium agreements
- guidance notes.

Note

The templates in the Toolkit are adaptable and Crown copyright, permitting use with acknowledgement of copyright and available from the Intellectual Property Office.

When setting out on an innovation path, it is important to:

- Identify innovations that are scalable. Ideally having multiple customers and applications in multiple growing market sectors and territories, for which the innovator can see accessible routes to penetrate them.
- Work out what IP is protectable. Protectable IP is necessary to justify investment in innovation.
- Be clear at the start of any research and development (R&D) collaboration on how it will be funded and how resulting IP will be owned, managed and exploited.
- Client-owned IP may be licensed to multiple manufacturers; consider providing or incentivising suppliers to invest in productivity improving tooling.
- Consider requirements for testing and certification – the cost to a supplier can be substantial. Clients with sector-specific requirements may consider contributing to such tests to accelerate adoption.
- Recognise that short- or medium-term capacity constraints may require suppliers to license other manufacturers to deliver their products for larger projects and programmes.
- Have a clear marketing communications strategy for disseminating information and learning about innovations. Organisations such as Buildoffsite and Constructing Excellence can assist with publishing case studies, but conference presentations, targeted continued professional development sessions, academic papers and advertising all need to be considered.

To invest in IP creation a business plans is often required along with the ability to protect the IP. It also needs time for development, testing, establishing manufacturing capacity and certifying products.

In this context, six main types of IP will be discussed here – copyrights, patents, trademarks, design rights, database rights, and trade secrets.

- Copyright is owned by the creating person or organisation and can be registered.
- Patents need to be applied for and awarded – the date of filing an application can be critical.
- Trademarks can be registered and need to be used.
- Design and database rights may be registered too.
- Trade secrets are protected by non-disclosure and non-compete agreements.

Contracts play a major role here for employers, employees, suppliers and purchasers, as IP may be assigned to specific parties or licensed for specific uses and territories etc.

In the past, protecting IP in the construction sector was perceived by some to be difficult, but this is not the case. The sector needs its stakeholders to get more strategic about managing IP if it is to generate and sustain the innovation it needs. This requires consideration of how the:

- development of IP can be funded
- owners of IP can be remunerated
- IP can be licensed
- use of IP may be specified in a client's, architect's or engineer's requirements
- products incorporating IP can be supplied in a healthy competitive environment.

Funding IP development

Small incremental steps may be funded within the normal delivery of a project. An example would include developing a concrete or mortar mix design for a specific purpose using established input materials and tests. Another could be applying known engineering principles to achieve a specific objective that has not been done before, such as designing a taller control tower at an airport. Product manufacturers generally fund incremental improvements to products to maintain competitive advantage.

The UK Government funds numerous R&D projects through UK Research & Innovation (UKRI), which is part of the Department for Business, Energy & Industrial Strategy (BEIS). UKRI comprises six research councils plus Innovate UK, which tends to fund most research in the construction sector. The research councils often channel their funding through specific sectors and university-based programmes. Innovate UK's Strategic delivery plan outlines the five 'themes' (future economy, growth at scale, global opportunities, innovation ecosystem and government levers) and six 'objectives' (people and careers, places, ideas, innovation, impacts and world-class organisations).[52]

Other funding includes:

- The UK Government provides a list of innovation competitions via the Innovation Funding Service.(53)
- Various 'catapults' also launch funding opportunities such as the Connected Places Catapult,(54) the UK's innovation accelerator for cities, transport and place leadership.
- Construction-specific competitions are launched periodically.
- Smart Awards are open to all sectors (and have a lot of competition for awards).
- Typically, the level of grants available depends upon the R&D classification and the size of the company; occasionally, innovation loans competitions are launched.

Creating new products requires either a proof of market study for a concept, or a major client or group of clients to issue a specification to meet a need and forecasts of expected demand for the solution.

Example of a collaborative sector wide offsite specification

The WIMES water treatment dosing kiosk, revised through the Buildoffsite Water Hub and the Pump Centre.(55)

Examples of collaboratively developed construction platforms

"On 26 November 2018, the IPA, in conjunction with the Department for Business, Energy & Industrial Strategy (BEIS), launched a call for evidence seeking views on a new approach to building". It proposed "that government uses standardised and inter-operable components from a wide base of suppliers, across a range of different buildings, as one way to drive efficiencies, innovation and productivity in the sector. This approach is called a 'Platform approach to Design and Manufacture for Assembly (P-DfMA)'.(56)

Subsequently, Innovate UK ran a funding competition, which resulted in the establishment of the CIH, which has run several projects, including a programme to develop a generic rulebook for the development and use of construction platforms. In doing this, it has analysed the needs of six UK Government departments (MoJ, MoD, DfT, DHSC, DfE, DLUHC) and rationalised them to enable the public sector to exploit those platforms.(57)

The CIH's Product Platform Rulebook launched in September 2022, is *"an open-access guide to support industry in building capability and capacity to develop infrastructure projects in the future"*.(58) The platform-based approach is by no means limited to the public sector; private sector clients are also adopting it.

Examples of collaboratively developed platforms in this programme include:

- Seismic and Seismic II: *"Seismic II project was developed by a consortium comprising consultancy blacc, offsite manufacturers Algeco, McAvoy, Tata Steel, the Manufacturing Technology Centre (MTC), the National Composite Centre (NCC) and Specific (part of Swansea University). The aim was to develop core components that could be used with the original Seismic frame – wall, flooring, ceiling and roof elements – thereby offering a full solution for clients across a range of sectors".*(58)
- The Forge: a collaboration between Landsec, Brydon Wood and Easi-Space to use a P-DfMA approach to create a configurable kit of parts used to design and construct.(59)

Organisations that are developing IP need to have sufficient margin generation or access to external finance to fund it. The construction sector's relentless pressure on keeping supplier's 'overhead costs' and consultancy fees to a minimum can prevent this. To sustain innovation alongside normal business operations requires a sustained charge in the profit and loss account. This can be measured as a % of revenue. In 2020, the average figures for the S&P500 included:(60)

- IT 11.4%
- Health care 10.2
- Communication services 5.2%
- Materials 1.4%
- Utilities 0%
- Real estate 0%

An analysis of UK manufacturers (excluding food, beverages and packaging) found an average R&D spend of 5.71% and manufacturing represented 72% in the UK.(62)

The NASDAQ reports that the top R&D companies, 7% to 22% of their sales revenue is on R&D. Given the nature of companies listed on the NASDAQ exchange, the higher levels are not surprising.(63)

The UK Government's sector strategies and related Innovate UK/EPSRC funding have created some significant increase in R&D activity, not least through the CIH, however the sector needs to build upon this.

Initiatives such as the Infrastructure Industry Innovation Partnership (iP3),(64) CIRIA,(65) and other research organisations' sponsored projects are helping too. However, innovation needs to become a normal part of all stakeholders' operations if real and sustained progress is to be made.

Example 13

Technik Floor

Floor screeds can take a long time to dry out and have a significant effect on project schedules. A collaborative venture involving Arup, Grants and Lindner developed a system, which delivers a 43% reduction in carbon, using 95% recycled material and reduced drying times by between four and eight weeks. This removes the need for a screed, and results in time related costs also being reduced[66] in a project's cost plan.

How can different stakeholders respond to this?

- **Clients**. Where large client organisations are able to sponsor R&D and the development of standard specifications, they need to take a view on how ownership of resulting IP will be managed so that there is a viable business case for both the client and the IP developer and ultimate product manufacturer(s). This is likely to include licensing the IP. An approach needs to be established at the beginning of the IP development process and recognise that other parties will be bringing background (existing) IP to most collaborations, and they will probably expect to share in future benefits from its exploitation.
  - For product designs funded by clients, the funding and ownership of specialised tooling and formwork may assist in managing the future use of the IP.
  - Specification of stretch performance requirements (possibly where there is only one known supplier that can meet them) can stimulate others to develop alternative means of achieving them, and allowing advances to be made while developing competition. It is important to consider the longer term.
  - Clients may collaborate to define specifications for new construction platforms (as described in the examples above).
  - As Bill Gates has pointed out, clients may need to pay a carbon reduction premium in the short term to enable innovators to progress down the product cost learning curve. He claims to be doing this with, for example, low-carbon aviation fuel but should be reduced over time.[90]
  - The easiest change to implement will be client led, with markets responding to demand. Such leadership often starts with a client's specification of requirements. These need to evolve and be performance/outcomes based if innovations are to be stimulated and adopted.
- **Quantity surveyors**. Reflect upon value in the wider sense, including all aspects from the client's perspective, including achieving their ESG targets. Also:
  - Consider the benchmark for R&D in assessing overheads.
  - Feed information regarding new technologies into benchmarking systems so that they are not only based upon historic data from established products and methods.

    - Do not be overly driven by historic spreadsheets and databases that suggest what a cost build-up should contain. The floor cassette case study contains important messages in this regard. Individual costs may increase in one part of a project to benefit other stakeholders later on; innovation may be a reason for this.
- **Designers.** Log IP developments, including background IP.
    - Consider how products and systems may be developed and configured for multiple applications for which a potential market has been identified.
    - Be clear on who is the design authority and what the permitted uses are for specific IP.
    - Review project management processes for product development (including quality function deployment, configuration management, failure modes and effects analysis, DfMA, traceability and testing, certification requirements, and after-market and end of life aspects).
    - Consider different approaches to licensing IP.
    - Consider the implications of climate change on historic assumptions and design norms.
- **Programme/portfolio managers.** Analyse the programme or project portfolio to identify areas of commonality and develop strategies to avoid reinventing and redesigning solutions to achieve the same outcomes, ones that also optimise ongoing asset management through rationalising maintenance needs, whole life carbon, whole life cost etc.
    - Become familiar with the CIH's Construction Quality Planning (CQP) that has been inspired by Advanced Product Quality Planning (APQP) used in other sectors. When BAA developed its family of standard products, it adopted such a system, courtesy of an aerospace company. It helped significantly with the establishment of reliable manufacturing arrangements.
- **Tier 1 contractors and integrators.** There is often not time to develop new products and technologies within the timeframe of a project, but innovations may help win contracts. This may involve backing a specific product or technology and assist in its development before it is deployed into projects.
    - Specifications need to be written such that both new and old technologies may respond to them, or if specific ESG objectives have been set, challenging targets to be met. These will tend to be performance based. That way there can be a healthy competitive market in which innovation and IP deployment provide competitive advantage.
    - There will be an increasing need to monitor the market for emerging technologies and understand how they may be applied.
    - They may play a significant role in enabling suppliers to increase in scale through prompt payment and recognition of the increased value that innovations deliver.

- They may also want to invest in specialised tooling and formwork so that they can deliver a portfolio of projects more economically and faster, but this will require have suitable cleaning, protection, transport, storage facilities to ensure durability and availability (as in the case of reusable formwork).

- **Manufacturers.** As for designers, plus:
  - Document IP as it is created.
  - A large part is likely to be know-how – often best protected by trade secrets.
  - Have a strategy for protecting IP. Both products and manufacturing processes may be patentable.
  - Specialised tooling can provide competitive advantage.
  - Consider licensing other manufacturers to increase capacity and accelerate market penetration.
  - Make sure new products are introduced smoothly, fully tested and certified where required. Become familiar with the CIH's CQP that has been inspired by APQP used in other sectors.
  - Drive innovations down the cost learning curve, through maximising cumulative sales volumes and continuous improvement reviews.
  - Look for opportunities to develop new products and collaborate to extend the options available within the framework of an established 'platform'.
  - Consider the use of distributors who are free to set their own prices so that there is not a single source/price for specific products.
  - Market benefits rather than uniqueness.
- **All stakeholders.** Consider technology route maps that the industry has developed for achieving net zero, such as the Green Construction Board's *Low Carbon Concrete Routemap.*(31)

Ownership and licensed use of IP

In construction, a lot of decisions are taken based upon where clients and other parties want risk to be managed. This is significant when it comes to specifying or using specific IP.

If a client sets out to own the IP of a product and then specifies that it is to be used on their project, then risks associated with using it may, to a large extent rest with the client. As the client is probably not an expert in the field of the product or its manufacture, and probably does not have day to day control over the supply chain, this is probably not the best arrangement for managing the associated risks.

Owning and needing the use of a requirement (rather than product) specification may be more appropriate for the client, as their needs become understood. Products are generally best managed by their designers and manufacturers (which may be the same organisation). Tier 1 contractors and 'integrators' may be tempted to try and control access to new technologies for short-term competitive advantage. However, this is likely to be counter-productive, as scaling up production and the range of applications a technology or product can address is likely to enable rapid cost reductions and provide greater benefits to all parties.

Offsite assurance schemes

10

Nigel Fraser, Buildoffsite

Buildoffsite was founded at a time when the offsite sector was mainly represented by SMEs, and some parts of larger groups with a wide range of performance and operating models. Some were little more than ‘construction in a shed’ while others were in the process of implementing lean manufacturing systems. There was a need to grow capacity and increase capabilities.

Buildoffsite aimed to drive and facilitate these changes and remove barriers to using offsite construction. Richard Ogden, the founding chairman of Buildoffsite, introduced Terry Mundy of Lloyds Register Quality Assurance (LRQA) to the Buildoffsite Executive and they decided to develop the Buildoffsite Registration Scheme. This would provide a framework with which different stakeholders could be assessed and demonstrate improvements over time. Early adopters supported the scheme, including the airports group BAA, a major and influential construction client. The Buildoffsite Registration Scheme was launched in 2007, with different streams for designers, manufacturers and installers.

The initial scheme started to gain traction with clients and suppliers, with major projects that typically had access to significant technical expertise, financial backing and direct relationships with insurers. However, it lacked aspects needed to develop the residential sector where insurers and lenders required assurance of future performance of construction systems over two thirty-year mortgage terms, totalling 60 years. Consequently, Buildoffsite convened a meeting with the Council of Mortgage Lender in 2010 at which the business concept for BOPAS was proposed, bringing together the expertise and services of Buildoffsite, LRQA, BLP and Allianz. The scheme’s design was endorsed in 2012 and BOPAS launched at the headquarters of the RICS in April 2013.

At the time of writing, 93 companies and construction systems have been listed on the BOPAS website as either accredited or progressing assessment, leading to BOPAS accreditation. The BOPAS website details a list of MMC providers, their scopes of work and associated accreditation status. The website also details the certified construction system linked to each MMC provider and the assessed durability of that system which may range from a minimum of 60 years to 100 years.

In parallel, in 2012 to 2014 LRQA developed a scheme for certifying a company’s BIM capabilities with reference to the UK Government’s emerging ‘Level 2’ BIM standards. Initially, it referenced national standards and specifications, and more recently with the ISO standards that have superseded them (BSI and BRE Global have also developed such schemes).

An extension of the BOPAS scheme, BOPAS+, has been developed which evaluates accredited organisations’ digitisation route maps. BOPAS+ was piloted in 2021/2022 and formally launched in May 2022.

Market and legislative drivers have changed over the last decade. There is now more focus upon:

- Zero carbon initiative – traceability of product and evidence of conformity, structured information.
- Regulation – digital transparency – means by which industry and society differentiate compliance/non-compliance.
- Golden thread – accurate and current digitally traceable product information.
- Construction Playbook[1] – collaborative working requires digital and cultural revolution – using a common data environment and portal.
- BIM – foundation for digital transformation.

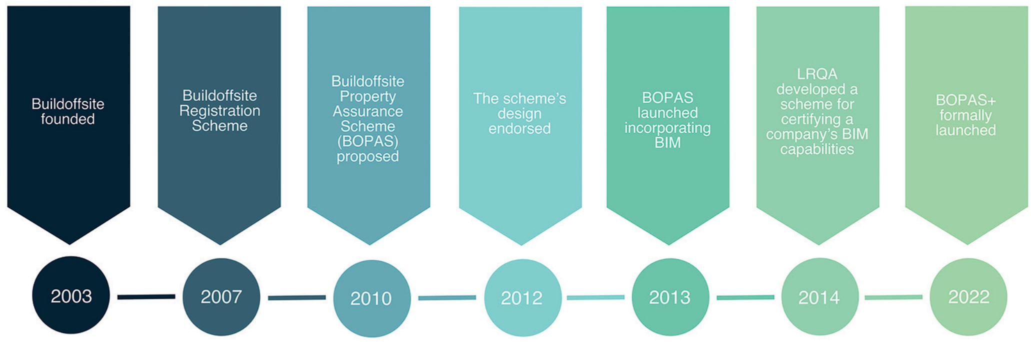
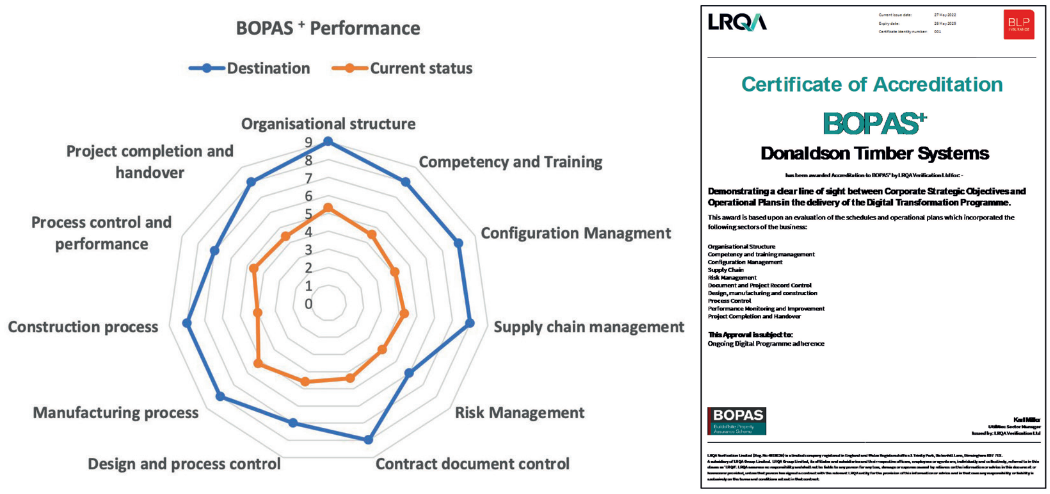


Figure 43 BOPAS scheme evolution

These factors have influenced the development of BOPAS+ from its original basis of demonstrating durability and rigour in the design, manufacture and installation processes (see **Figure 44**).

Note that values are indicative of the process and not linked to any individual company.



a *b*

Figure 44 BOPA+ performance evaluations (a) and an example BOPAS+ accreditation certificate (courtesy LRQA)

The bulk of BOPAS and BOPAS+ accredited organisations exist in the residential construction sector but are not limited to that sector.[67]

In recent years, other offsite evaluation processes have or are being developed in the UK, including the National House Building Council (NHBC) Accepts, and the BRE's approach to certification by developing BPS 7014.[68]

BPS 7014 has now been through a consultation period and *"This BRE Product Standard (BPS) 7014 has been developed to provide a route to certification for offsite/modular construction for use as residential buildings. The Standard sets out performance requirements in a number of technical areas. Some of the requirements are mandatory, such as for fire and structural performance, and are required to demonstrate regulatory compliance. Other performance assessments are voluntary."*[68]

An NHBC Accepts logo shows that an innovative system has been rigorously assessed and that they consider it to meet their standards. It also demonstrates that, subject to appropriate design and installation, the system can be used in homes covered by their warranty products. NHBC do state that it is not an accreditation system.[69]

While the development of standards should facilitate the introduction of innovations, there have been concerns within the industry that it would become expensive for companies to be assessed by multiple organisations with different criteria. Initiatives have been evolving to harmonise requirements.

This is also a period of renewed interest and activity in the development of standards relating to offsite construction. In addition to the draft BRE standard mentioned (BPS 7014), the International (ISO), European (CEN) and British (BSI) standards organisations are all developing relevant standards.

The UK's input and domestic standards are developed through the BSI committees. Notably:

- *CB/301 technical committee offsite and Modern Methods of Construction* has mapped out how will proceed with its task of supporting the ISO TC/59's[70] revision of standards for prefabricated buildings.
- *B/558/01 Circular Economy in the construction sector* is supporting the CEN/TC 350/SC 1[71] developments at the European level.
- *B/555 Construction design, modelling and data exchange*[72] for all things BIM.
- Other revisions to standards are increasingly including more content relating to offsite construction and the wider subject of MMC, not least those relating to BS 5606:2022[5]. The built environment safety competences requirements in PAS 8671:2022, PAS 8672:2022 and PAS 8673:2022[73, 74, 75] will also help drive change in the sector.

Assessment and accreditation systems will need to keep abreast of these developments.

Evolving procurement processes

11

At the workshops held during the development of this guide, several key points were raised, including:

- Aiming for offsite from the start – designers need to be encouraged to tap into what is available and design around this.
- Specification of performance and outcomes rather than specific designs.
- Use of standard details particularly at interfaces – platform-based approaches.
- Frameworks with multiple tier suppliers can be advantageous for repeat clients.

Other points worth considering:

- Understanding sector's offerings, capacity and early design input to keep offsite options open.
- Some constraints can be a useful creative stimulus – a blank canvas can be harder to start from.
- Clients are often procuring 'entire programmes' not individual projects. There are opportunities to develop product and platform-based approaches.
- New standard contracts and approaches are increasingly being used, including:
  - **Framework Alliance Contracts.** FAC-1 Framework Alliance Contract *"covers processes and relationships not dealt with in any existing standard form. It is a multi-party over-arching agreement between any number of framework alliance members."*(76)
  - **Term Alliance Contracts.** TAC-1 Framework Alliance Contract: *"is a versatile standard form term alliance contract which supports and integrates the provision of any type or scale of works and/or services and/or supplies."*(77)
  - **ICE's Project 13** Moving from transactions to enterprise for infrastructure delivery(78) – an *"industry-led response to infrastructure delivery models that fail not just clients and their suppliers, but also the operators and users of our infrastructure systems and networks."*
  - **Single project insurance** can assist in changing behaviours and help ensure optimal solutions to a wide range of issues.

Systems engineering learning when using offsite solutions

Nigel Fraser, Buildoffsite

The use of systems engineering methodologies, is becoming apparent in the construction sector, for example, with the need to co-ordinate onsite and offsite works and the emergence of the enterprise integrator in the Project 13 model.(78)

- Specifications need to be linked to what represents value to the client – the recorded basis for design decisions.
- More focus on the physical and timing interfaces between project deliverables/ packages (both for design outputs and products).

- The project integrator needs to have rigorous change management control over these interfaces, with clearly defined design authorities to approve requests for changes.
- Project packages assigned to the party that is best able to manage the associated risk, not the lowest member of the supply chain/matrix.
- The project integrator needs visibility of the on-site, in-factory and in-transit status of project deliverables.
- Onsite staff need to be trained to understand how the logistics and assembly process has been planned.
- The programme management and the site logistics go hand in hand for offsite and needs to become more automated.
- Suppliers cannot always meet delivery dates – projects still need some contingency plans.

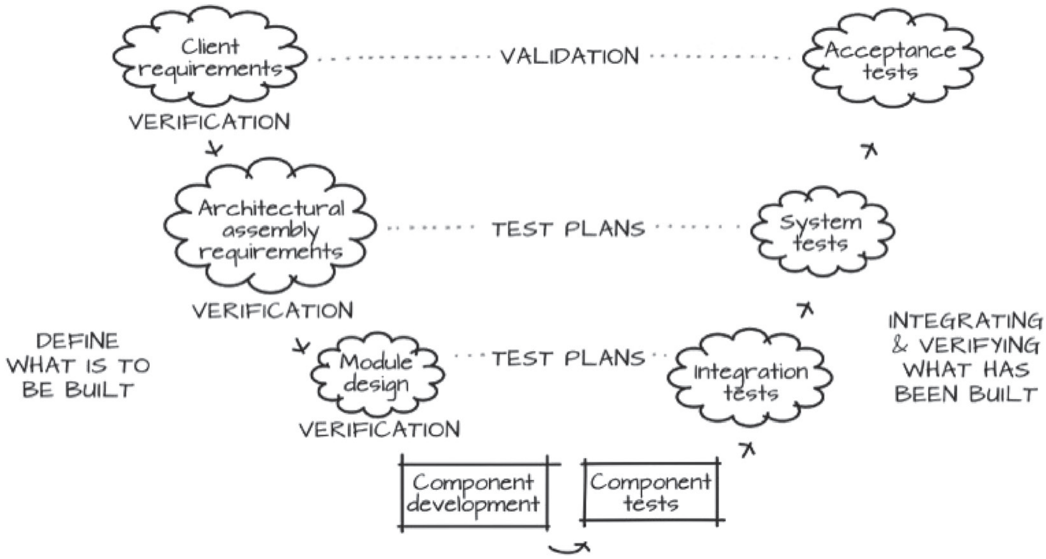


Figure 45 A simplified systems engineering V-diagram applied to construction

Case study 12

How Project 13 applies a systems engineering approach to the wider 'enterprise' to deliver infrastructure

Project 13 is a new delivery model from a partnership initiative of the ICE. Its aim is to allow an enterprise to maintain infrastructure efficiently rather than through the traditional transactional approach defined by five pillars and a set of principles.

"An enterprise brings together owners, partners, advisers and suppliers, working in more integrated and collaborative arrangements, underpinned by long-term relationships. Participating organisations are incentivised to deliver better outcomes."(78)

It is a radically different approach but one which is proving to be popular with those who have embraced it.

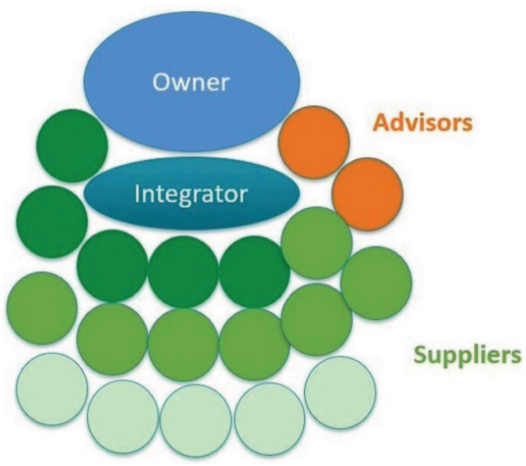


Figure 46 Project 13: the enterprise approach (courtesy Project 13/ICE)

Five Pillars	Principles
Capable Owner	○ Owner develops Enterprises built on long term business to business (b2b) relationships ○ The Enterprise is set up to deliver: - Clearly articulated customer outcomes - Long term asset performance
Governance	○ Value is defined at outcome level (through baselines, benchmarks or affordability) ○ The Enterprise is rewarded for outcome performance ○ Risk allocation is aligned with capability and where possible jointly owned ○ The commercial arrangements provide the potential for sustainable returns ○ There are clear incentives and opportunities for investment
Integration	○ The Integrator brings together capabilities that deliver effective solutions through production systems ○ The Integrator enables a platform approach to delivery ○ Supply systems are organisationally and commercially aligned with the outcomes to be delivered ○ The Enterprise has a common and committed approach to health, safety and wellbeing
Organisation	○ The integrated Enterprise is aligned with the outcomes to be delivered ○ Supplier capability is engaged early in developing solutions ○ The Enterprise integrates the required capability in high performing, collaborative teams
Digital Transformation	○ The Enterprise digital transformation strategy enables an integrated digital approach to asset management and delivery. ○ The Enterprise effectively integrates engineering and digital technology to deliver intelligent solutions ○ Data and information are recognised and treated as digital assets that enable customer outcomes

Figure 47
Pillars and principles (courtesy Project 13/ICE)

Digital twins and offsite

12

Casey D Rutland, Digital Green,
Richard Kelly, buildingSMART International
Nigel Fraser, Buildoffsite,
Mark Coates, Bentley Systems

Introduction

The term ‘digital twin’ means different things to different industries. A digital twin is a virtual representation of a thing or process. In the built and natural environment, it can be one of these things or both. The ‘static’ virtual representation of the thing or process is best embellished with ‘dynamic’ data, which provides feedback from its latest state based on business data or sensor data.

Invariably, a digital twin in relation to OSM, will often include a 3D virtual representation of a building component, system or complex modular unit.

Equally, in the infrastructure sector, different types of digital twins can be seen at different stages of a built asset’s lifecycle – whether during the feasibility stage, design and construction, or throughout operation. A digital twin can be hugely beneficial for making better informed decisions that provide better outcomes.

UK context

When it comes to raising awareness and promoting the benefits of digital twins, much work has been undertaken in both the UK and abroad. The Centre for Digital Built Britain (CDBB) published the *Gemini Principles* in 2018,[99] with the primary aim to ensure that digital twins, which may in future contribute to the UK national digital twin, should have clear purpose, be trustworthy and function effectively, as shown in **Figure 48**.

Figure 48 The Gemini principles

The CDBB National Digital Twin (NDT) programme aims to create an ecosystem of digital twins, providing an opportunity to increase value by using data to benefit the public. The NDT is primarily a UK government proposition to help improve understanding of UK infrastructure, and it will include built assets in one form or another.

As a progression of these industry-generated resources, the BSI have published Flex 260: v1.0 2022-01.[100]

Whilst the NDT programme is well-respected, Flex 260 places digital twins and their benefits in the context of business as either discrete twins or connected twins that are more relatable to the private sector.

Where does BIM fit with digital twins?

According to the BS EN ISO 19650 suite of standards, BIM is the process of delivering structured data about built environment assets through their lifecycle. The suite enables a combined capital expenditure (CapEx) and operational expenditure (OpEx) process, consisting of the following:

- The client considers the use case and purpose.
- The client defines what information is needed and to what standards (including cyber and physical security).
- The client appoints the team with the relevant contract amendments to cater for live data delivery.
- The team plans the information delivery.
- The team delivers the information at various project or programme stages to open, published standards.
- The information is verified and validated.
- The accepted information is handed over as the asset information model and is used for operation.
- Further OpEx information updates are included.
- Future CapEx project information is combined into this dataset through the lifetime of the asset.
- The dataset is used during final refurbishment or demolition.

This process is more concisely known as:

Specify **Procure** **Deliver** **Assure** **Store** **Present** **Exploit**

These steps are almost identical to the ones required for good practices in creating a digital twin. The difference between digital twins and static BIM deliverables (structured data, eg reports, databases, drawings, specifications, surveys, models, and calculations, such as the asset information model) is the addition of dynamic 'right-time' data.

The relevance to OSM

As a cutting-edge building approach, OSM has the ability to embrace advanced industrial production systems through a more organised workflow, standardised goods, and robotic automation; enabled through better data – and information – management.

The use of a digital twin is important for OSM because it allows production to be represented electronically and graphically with all associated activities, resources, and processes. As a result, critical information in the product manufacturing and on-site assembly processes may be examined such as cost, time, waste and environmental implications.

The data needed for accurate outcomes and better-informed decision making comes in a variety of forms such as databases, written narratives and BIM models. It also comes from other domains, many of which are already in use but are less connected and less interoperable than they could be. Software-agnostic ecosystems of connected data are developing rapidly through the creation and application of buildingSMART International's openBIM® standards. By incorporating these standards, multiple companies in a complex supply chain can share data and make it available for the life of the built asset, regardless of the longevity of individual software companies.

The client decision makers can then choose more innovative solutions, with greater assurance, as this interoperable network of software makes the design outcomes more accessible.

Incorporating semantic web technologies, such as linked data and web ontology language (WOL) models, has been shown to be more effective in addressing these issues, particularly in terms of interoperability and clear knowledge representation.

Digital twins are growing in importance. IBM[(91)] states:

"A fundamental change to existing operating models is clearly happening. A digital reinvention is occurring in asset-intensive industries that is changing operating models in a disruptive way, requiring an integrated physical plus digital view of assets, equipment, facilities, and processes. Digital twins are a vital part of that realignment.

The future of digital twins is nearly limitless, since increasing amounts of cognitive power are constantly being devoted to their use. So digital twins are constantly learning new skills and capabilities, which means they can continue to generate the insights needed to make products better and processes more efficient."

Digital twins support many critical industry challenges, including ESG reporting, and action such as monitoring and reporting energy use, carbon dioxide emissions, asset condition, maintenance and history of refurbishment. A fabric-first approach and a digital twin may help ensure that performance is maintained or even improved during the life of an asset.

In response to both contractual and financial requirements, information can be gathered and analysed, and control functions can be specified for delivery by projects.

New regulations are requiring project funders and investors to report upon the carbon profile of their clients.

Asset handover from the constructor to the owner-operator or facility manager will require the information to assure safety: the beginning of the 'golden thread' or 'loop' of information.

A digital twin is also likely to support asset value optimisation and informed due diligence at the point of sale, providing the digital history of asset components and their current condition.

The OSM process is an ideal place to benefit from two functions of digital twin; one internally facing, bringing efficiencies and benefits to the manufacturing process, and the second by creating a digital representation of the built, maintainable asset (comprising various built systems) for use throughout the operational lifecycle.

Digital twin use cases

As with any digital transformation initiative, it is important to always understand the 'why'; what problem is the new initiative solving? How can the new way of working be repeated, scaled, and normalised?

For offsite considerations and many others, work has been undertaken to help organisations understand their particular use case(s); Flex 260 contains a list of typical use cases.

For offsite construction, the following could be considered:

- design digital twins to optimise material use
- fabrication digital twins to feed design data directly into the fabrication machines on the factory floor
- process digital twins to identify efficiency savings in manufacturing
- process digital twins to streamline supply chain deliveries and operations
- at handover, provide as-manufactured data for inclusion in the overall built asset.

These are just a few of some high-level digital twin uses specifically benefiting the offsite industry. However, it should be noted that offsite operations do not sit in isolation; the fabricated 'units' contribute to a broader built asset. It is recommended that the digital units are as compatible as the physical units themselves.

So, consider the digital twin use specific to requirements, ie a catalogue rather than a single outcome. Although creating such a catalogue can seem daunting, it is recommended to begin with a simple use case and build complexity as understanding matures and competency increases.

National digital twin business case resources

During their funded work, the CDBB created and published free resources that help businesses with vital first steps. As previously discussed, digital twin use cases are wide and varied, driving the apparent confusion as to what a digital twin is. However, their variability is also a strength, depending upon the case, which specific to a particular organisation to solve a particular challenge. A digital twin needs to have a clear purpose.

Libraries of use cases are being developed and shared, with offsite construction often a key component. Once an organisation's case is understood, the CDBB Digital Twin Toolkit(101) can be used. The toolkit is a suite of free tools that enable stakeholders to critically assess use cases, in strategic, financial, managerial, socioeconomic and commercial terms.

Value

When considering overall value, the toolkit suggests using a Five Capitals model,(111) whereby the following items are considered to ensure extending beyond the singular cost model to an holistic approach to value:

1. **Natural** – environmental impact and resource use.
2. **Social** – influence on citizens and the community.
3. **Human** – safety, security, and effects on jobs.
4. **Manufactured** – impact on production and productivity.
5. **Financial** – capital and operational costs and revenue.

These aspects are recommended as key components of any offsite business model, whether a spin-off operation from an established firm, a vertically integrated model, or the use of product design methodologies in a digital systems integration model(8). They can help improve pre-manufactured value and help to make the case for digital twins as an enabler of accelerated adoption of OSM.

The importance of standardisation and interoperability

As the construction industry moves towards a digital-first approach to various challenges, it is clear that data forms part of that discussion and enables understanding of what is available and what needs to change, and at scale. If these data sources are to be of optimum benefit at scale they should be trusted and able to be created and consumed by different software, reliably.

In simple steps, the CDBB Digital Twin Toolkit[101] recommends having:

1 A clear purpose for the digital twin, such as one or more use cases.
2 Data relating to the physical twin, whether directly measured or inferred.
3 A format for using that data, such as a model.
4 The ability to use the digital twin to influence decisions and consequent interventions.
5 A way of connecting your digital twin with others to generate added insights and benefits.
6 (Optional) An idea of what the digital twin could achieve in the future.

Points (2), (3) and (5) are addressed through the design, construction, and handover processes according to the UK BIM Framework[102]. The Framework focuses on information management, collaboration, and the handover into the operational phase of a dataset structured for use in an asset information model. By standardising the process, relationships between stakeholders are understood and the data and information supplied by each party is reliable.

The delivered asset data is not buried in 'digital paper', but provided in a way to assist the automated import of all relevant data, certification and information about each maintainable asset. This data will be used for purposes defined at the beginning of the project by the operator and will support various decisions throughout the lifecycle. So, it is common sense that the data has longevity and is secure, standardised, supported and interoperable.

Interoperability

As defined by the UK Government and Industry Interoperability Group (GIIG),[103] interoperability is:

> *"The ability of two or more systems to exchange information securely and to use the information that has been exchanged. (This exchange must not require additional processing and must not be legally or technically restricted to specific software solutions.)"*

In OSM, many projects will include manufacturing building components, systems, or whole units; in the operational phase, these items will be maintained as a whole or potentially at their lowest level component. Interoperability requires that the data held about those maintainable components needs to be interoperable and digital.

Industry Foundation Classes (IFC) are a global standard for describing the physical attributes of almost any component in the built and natural environment[104].

buildingSMART International

buildingSMART is the worldwide industry body driving the digital transformation of the built asset environment. It is committed to delivering improvement by creating and adopting open, international standards and solutions for infrastructure and buildings.

At its core, buildingSMART enables the entire built asset industry to improve the sharing of information throughout the lifecycle of project or asset. By breaking down the silos of information, end users can better collaborate and cooperate regardless of which software application they are using. buildingSMART's technical core is based around Industry Foundation Classes (IFC) which was ISO certified in 2013.

IFC is a standardised, digital description of the built asset industry. It is an open, international standard (ISO 16739-1:2018) and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases.

As the leading method for describing the physical and mostly static aspects of an asset, it is highly recommended that any stakeholder looking to digitally describe any built asset should use IFC and the resources provided by buildingSMART International(105, 106, 107).

While this addresses the digital twin's static data, what about its dynamic data?

Dynamic data + context = virtual representation of the physical

The previous sections addressed the static description of assets, as well as how digital twins will often add dynamic data streams of varying frequency to that data. Dynamic data may come from commercial business systems, as well as the more often considered sensor data.

The data all have their own range of standards, and they are specific to the data collection type and the data type itself. Much work is being undertaken by the relevant bodies to streamline and standardise globally, but there are still competing protocols for communication. However, sensors provided with context work better than those without.

Digital twins are habitually described in the context of sensors, and those sensors form part of a network. They take valuable measurements and know their position on a network, perhaps which room they are in or what rail signal they refer to. But the question is whether they have enough context to be as valuable as they could be, and if they provide an accurate picture of reality.

While many use cases may be simpler and not require as much detailed context as others, there is a need for overall building performance to be understood in its entirety, rather than by sensors alone. The next step is to take action to resolve any anomalies.

Opportunities for OSM

When included in the digital twin use case, sensors can be preloaded with data about their context through the OSM process. When installing them in the factory, the data about the sensor or system can contain properties that include what space they occupy or serve, what building element they are mounted in (eg wall, floor, celling or door), what system they are connected to, or what geographic orientation they face. This information provides the sensor with context, which can be used to better understand the provided data stream.

Summary

Benefits

The benefits of open digital information flows are that where an organisation sits within the hierarchy of asset management, and at whatever stage of the asset lifecycle, the right people will be able to access the right information with an appropriate level of detail.

As a result, everyone can make better decisions about the design, build approach, functionality, criticality of certain elements, and predicted performance of the buildings. During operation, it will be easier to establish how the building is performing, have essential maintenance regimes in place and much clearer instructions about when and how to replace products.

The success of the offsite construction industry relies on the early engagement and selection of the offsite designers and manufacturers. Too often, the offsite option is discounted at the earliest stages of specification as being too risky from a cost and supply chain perspective; it is difficult to predict how new combinations of products will perform when combined into a fresh system.

In a scenario where it is possible to identify all elements of a building, ie in terms of their geometry, performance, the work they do, and materials, it is possible to understand how the elements interrelate with their surroundings and connected products.

The application of buildingSMART International's openBIM® (processes applies at all levels of a built asset's metabolism and structure, ie the portfolio of assets in an estate, the facility, the system and individual products.

The aim is to create multiple connected data environments, which are interoperable, so that information is relatable about all levels in the assets scope.

Having a whole life view of all expenditures (CapEx + OpEx) can not only provide leaders and organisations with greater transparency into operations and project delivery, but also help provide more opportunities to realise better commercial and sustainability results.

Case study 13

Ponsteiger building, Amsterdam

The Ponsteiger building is an apartment building of luxury and key worker homes that is built on reclaimed land in Amsterdam. The decision to build to an enhanced quality within the original budget was enabled by having all the building information available before production. It was delivered using entirely offsite solutions through the management of hundreds of dynamic models that was only possible due to the use of buildingSMART International's openBIM® processes and collaboration.

For more information go to: **https://www.buildingsmart.org/bouwcombinatie-pontsteiger/**

There are an increasing number of examples of the benefits of connected data environments, such as the Ponsteiger building project (**Case study 13**).

Digital twins are an outcome of an ecosystem of connected data, quality assurance and trust.

A true digital twin will give right-time updates on how the actual facility is working, which requires installing sensors and other back indication devices that are reporting digitally (the IoT).

Although much of the technology already exists, or could easily be created if there was a demand, they will not be applied until there is a coherent digital ecosystem to make them useful. As ecosystems grow and become more mature, so will the decision to apply insight devices, making the reality of true digital twins ever more common.

As the industry begins to trust the emerging situation, they will choose to fit insight devices and monitoring sensors, which will feed right-time data into the evolving connected data systems.

Another example of a digital twin is the Climate Resilience Demonstrator (CReDo).(112) It involves the Connected Places Catapult working with Anglian Water, UK Power Networks and BT.

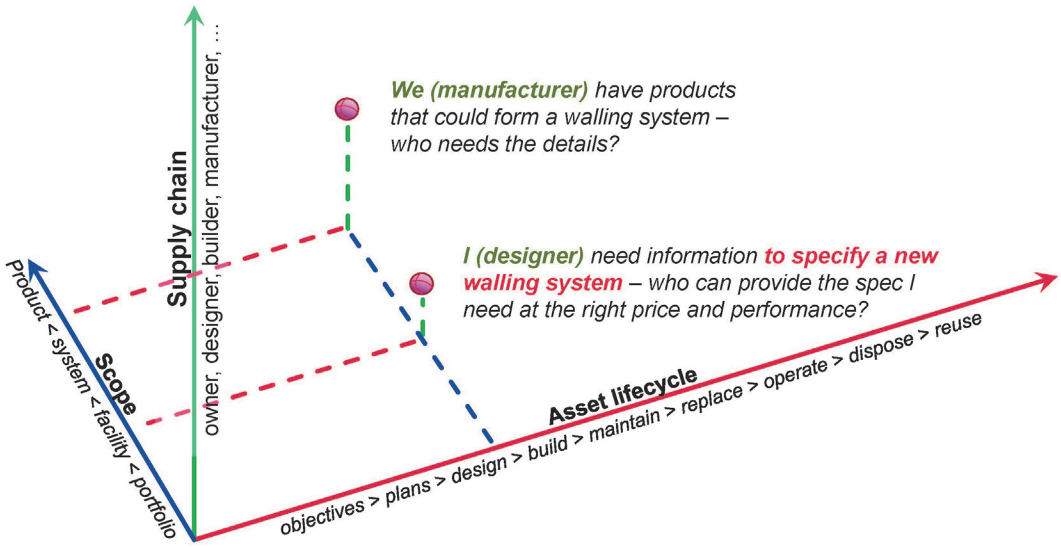


Figure 49 Digital environment in three dimensions (courtesy buildingSMART International)

Case study 14

Use of digital twins to combat corrosion

In 1998, Sir John Egan's *Rethinking construction* report[108] identified the future importance of data, which is being brought to life now in many ways on the construction site. This was expanded by Graeme Jones[109] in 2000 to show where interoperable open networks may be used as neural networks to inform improved maintenance and control of corrosion. Since then, some owners of structures have benefited from having databases that provide the basis for recording, analysing and optimising the status and performance of their structures, along with the potential to characterise structural resilience, extend and predict usable life and underpin security.

Figure 49 summarises options to provide data informing a wide range of functionality that may be required of a steel reinforced concrete structure.

Sensors and control systems can be added (bound) to open networks, physically installed by embedding within and on to the structure. The use of open standard protocols allows online access for decision making and minimising ongoing costs of maintenance. Data leading to outcome can have a societal benefit such as minimising road and rail network disruption by avoiding degradation to the infrastructure.

The ICCP components that are embedded into the structure may be incorporated into offsite, pre-cast, sub-assemblies, using either individual elemental components or modular units that have been designed for ease of assembly, including modular anode units and modular wiring.

Using open systems also allows for the integration of other asset management systems (such as lighting, security, energy performance) and component competitiveness, enabling access to multiple vendors.

Case study 14 (contd)

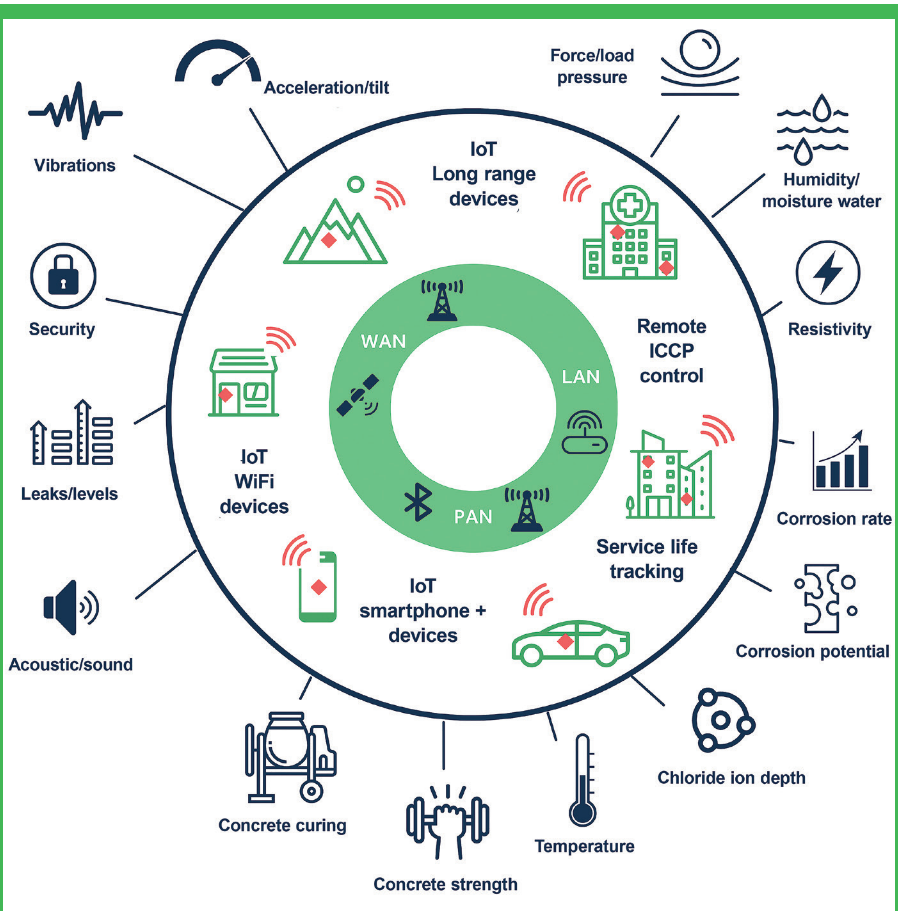


Figure 50

Schematic summary of sensing and control for steel reinforced concrete structures

Developing such a resilience digital twin also permits strategising for future upgrading of the asset or its digital twin, thereby maintaining best value and most relevant interoperable management of the needs of the structure as technology evolves.

For corrosion monitoring, management and control, as part of structural healthcare, some data are logged daily (power and sensor potential), some weekly (instant-off potentials), and others monthly (potential decay and corrosion rate), in accordance with BS EN ISO 12696:2022.[110] The ICCP system is powered all of the time with data transfer scheduled and decisions made to control, periodically, typically monthly.

The resulting database constitutes one part of a facility's wider digital twin and may be integrated with other data models, facilitated where open system protocols are used.

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Whole life carbon explained

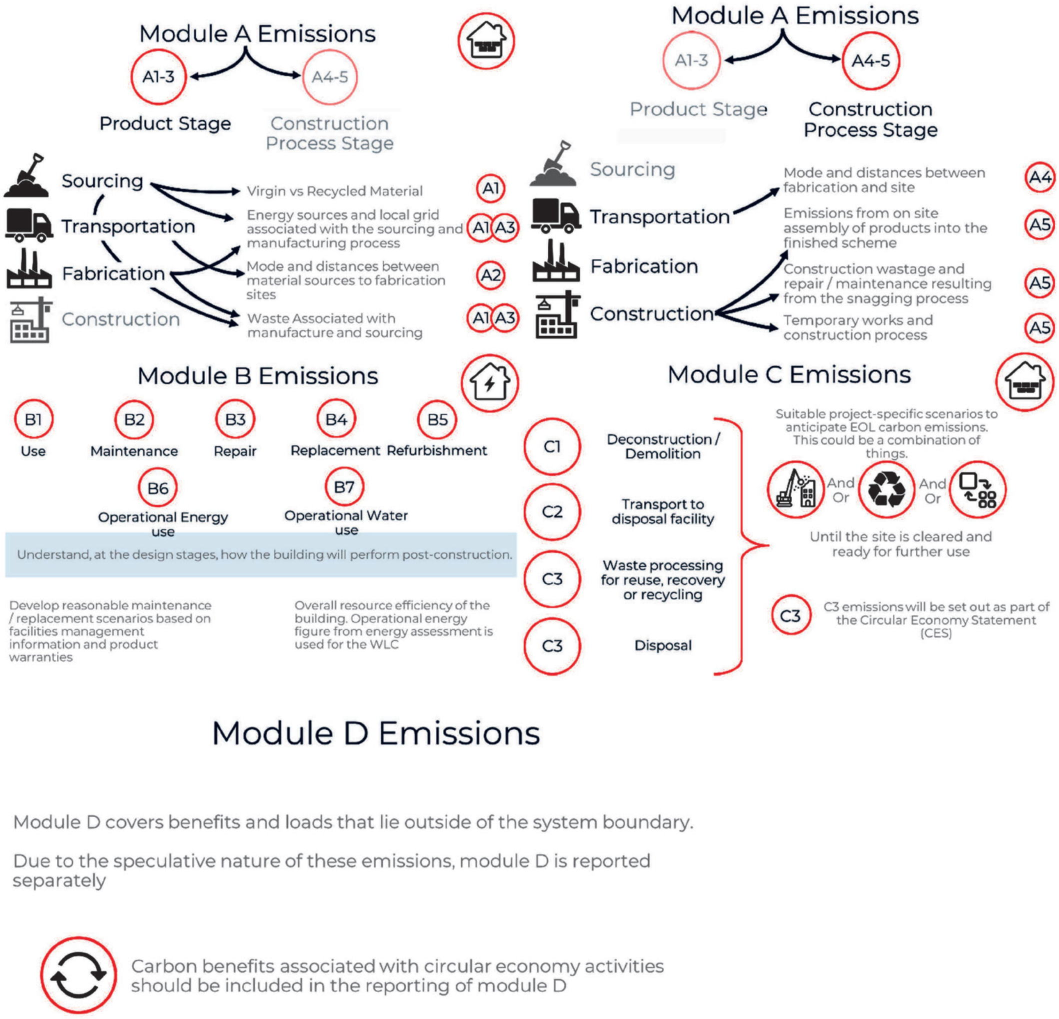

Figure 51 Whole life carbon assess ment – project life cycle information

A1

Reducing whole life carbon

London Energy Transformation Initiative (LETI) proposes the following measures to reduce the whole life carbon of a development:

- Define the energy and embodied carbon targets, as well as whole life carbon measurement and verification process at project conception and track throughout. Formal disclosure should be made at post-completion and then annually.
- Use whole life carbon analysis during design to optimise embodied carbon, reduce operational energy and integrate Circular Economy principles. For example, testing energy reductions, increased envelope specification or calculating carbon payback periods for MEP equipment or renewables.

Lilian Martins, WSP

- Address upfront embodied carbon emissions (A1-5) by using minimal material. Consider the carbon cost/benefit between upfront carbon, operational carbon and life cycle carbon due to replacement cycles.
- At each replacement cycle, prioritise low-carbon materials and Circular Economy principles to reduce whole life carbon emissions.
- Operational energy loads must be minimised and meet local energy targets; for example LETI energy use intensity (EUI) targets.[25] A future decarbonised grid depends on reducing overall energy requirements. A further effect of grid decarbonisation is to make embodied carbon an even larger proportion of whole life carbon.
- Use Circular Economy principles at the beginning and end of the building and component life cycle. This includes retrofit, reuse of materials, recycled materials, and design for future adaptability. Document end of life scenarios and quantify the potential future carbon benefits.

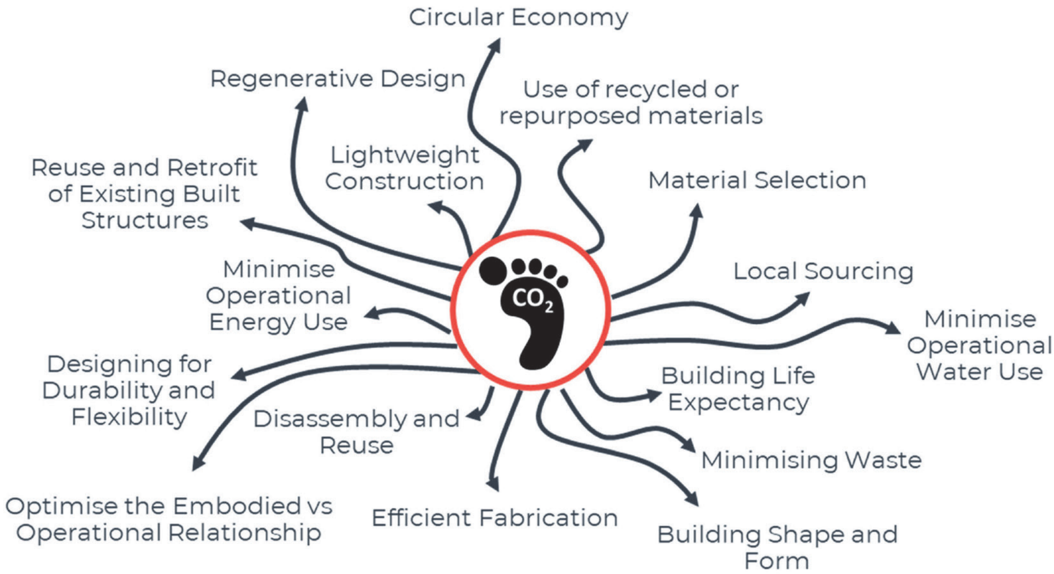

Figure 52 Holistic approach to whole life carbon and Circular Economy (courtesy WSP)

Whole life carbon and RIBA stages

The RIBA Stages demonstrated in **Figure 53** are beneficial benchmarks for determining the strategic and sustainability aspirations of a project. whole life carbon thinking should be embedded throughout the design process from Stage 0 to Stage 7. Low carbon choices selected in the earlier stages in the project are less financially strenuous than attempting to make changes later which may incur large costs (financial, time etc).

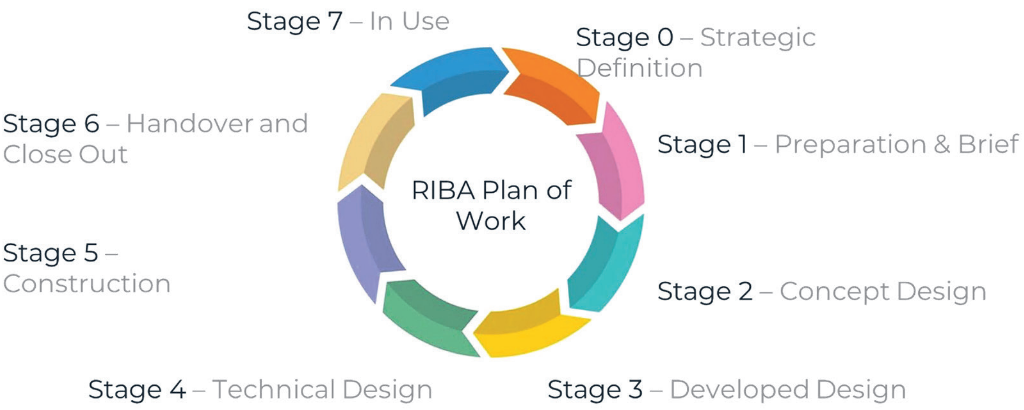

Figure 53 RIBA Plan of Work stages (courtesy RIBA)

Whole life carbon hierarchy

The Greater London Authority has published whole life carbon principles[92] to be used throughout project life cycles:

1 Reuse and retrofit of existing built structures.
2 Use repurposed or recycled materials.
3 Material selection.
4 Minimise operational energy use.
5 Minimise carbon emissions associated with operational water use.
6 Disassembly and reuse.
7 Building shape and form.
8 Regenerative designs.
9 Designing for durability and flexibility.
10 Optimisation of the relationship between operation and embodied carbon.
11 Building life expectancy.
12 Local sourcing.
13 Minimising waste.
14 Efficient construction.
15 Lightweight construction.
16 Circular Economy.

The Infrastructure Carbon Review 2013[79] published a hierarchy of carbon reduction potential (see **Figure 54**).

- Build nothing – challenge the cause and explore alternative approaches to achieve the desired outcome.

- Build less – maximise the use of existing assets and optimise asset operation and management to reduce the extent of new construction required.
- Build clever – design-in the use of low-carbon materials, streamline delivery processes, minimise resource consumption.
- Build efficiently – embrace new construction technologies, eliminate waste.

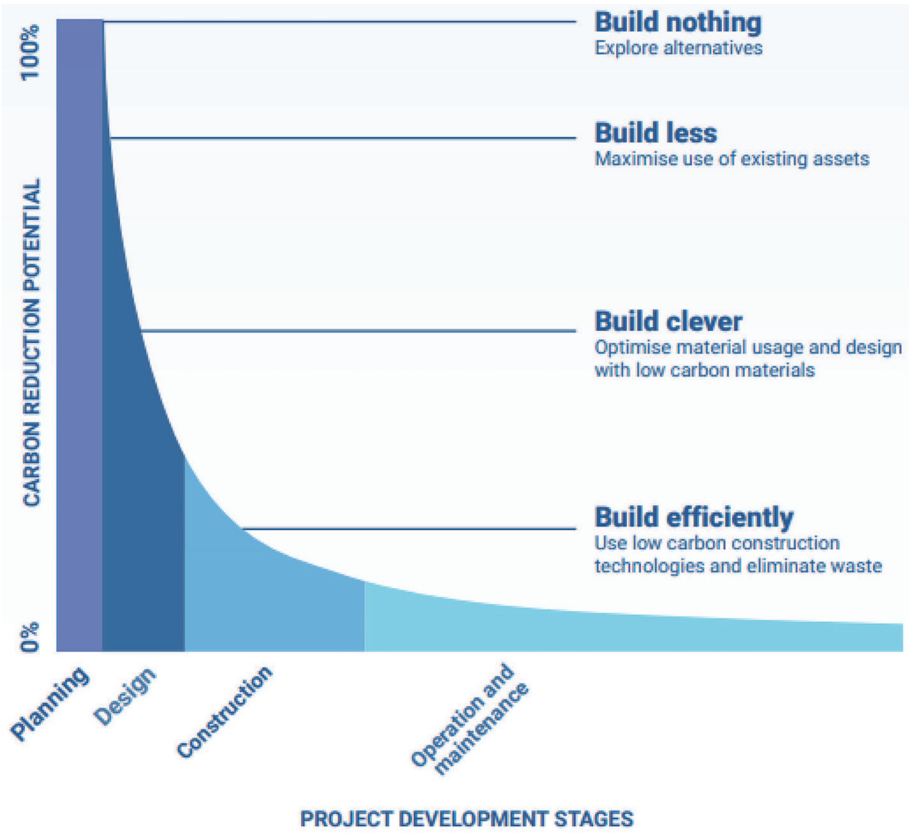

Figure 54 Hierarchy of carbon reduction potential

Operational and embodied carbon targets

To assess the future projection of embodied carbon targets and operational energy targets, WSP have created the tables in **Figure 55**, which demonstrate the varying future targets set by established organisations such as LETI, the UK Green Building Council (UKGBC) and RIBA. The embodied carbon and operation energy targets have been separated into different building typologies to better understand the targets for different building uses. These operational energy targets include both regulated and unregulated energy, a variable that is not accounted for in current building regulations.

UPFRONT CARBON, A1-5 (exc. Sequestration) - kgco2e/m2

	Band	Office	Residential	Education	Retail
	A++	<100	<100	<100	<100
	A+	<225	<200	<200	<200
LETI 2030 DESIGN TARGET	A	<350	<300	<300	<300
	B	<475	<400	<400	<425
LETI 2020 DESIGN TARGET	C	<600	<500	<500	<550
BASELINE FROM UKGBC for RESIDENTIAL	D	<775	<675	<625	<700
BASELINE FROM UKGBC FOR OFFICES AND LETI BUSINESS AS USUAL <800 FOR RESIDENTIAL	E	<950	<850	<750	<850
LETI BUSINESS AS USUAL <1000 FOR OFFICE	F	<1100	<1000	<875	<1000
	G	<1300	<1200	<1100	<1200

EMBODIED CARBON, A1-5, B1-5, C1-4 (inc. sequestration) - kgco2e/m2

	Band	Office	Residential	Education	Retail
	A++	<150	<150	<125	<125
	A+	<345	<300	<260	<250
	A	<530	<450	<400	<380
RIBA 2030 BUILT TARGET	B	<750	<625	<540	<535
RIBA 2025 BUILT TARGET	C	<970	<800	<675	<690
	D	<1180	<1000	<835	<870
"BUSINESS AS USUAL"	E	<1400	<1200	<1000	<1050
	F	<1625	<1400	<1175	<1250
	G	<1900	<1600	<1350	<1450

OPERATIONAL ENERGY WHOLE BUILDING – kwh/m2

	Office			Residential		Education	
	UKGBC	RIBA	LETI	RIBA	LETI	RIBA	LETI
Standard	90	75	-	60	43	70	-
Net Zero Carbon Targets	55			35		60	65
GIA or NIA	*GIA*	*GIA*	*GIA*	*GIA*	*GIA*	*GIA*	*GIA*

UKGBC Operational Energy Performance Targets for NZC - Office

Scope	Metric	2020-2025	2025-2030	2030-2035	2035-2050
Whole Building Energy	kWhe/m2 (NLA)/year	160	115	90	70
	kWhe/m2 (GLA)/year	130	90	70	55
	DEC Rating	D90	C65	B50	B40
Base Building Energy	kWhe/m2 (NLA)/year	90	70	55	35
	kWhe/m2 (GLA)/year	70	55	45	30
	NABERS UK Star Rating	4.5	5	5.5	6
Tenant Energy	kWh2/m2 (NLA)/year	70	45	35	35

RIBA Operational Energy Performance Targets for non-domestic

RIBA Sustainable Outcome Metrics	Business As Usual	2025 Targets	2030 Targets
Operational Energy kWh/m2/year	130	<75	<55
DEC Rating	D90	B50	B40
NABERS Rating	-	5	6

RIBA Operational Energy Performance Targets for domestic

RIBA Sustainable Outcome Metrics	Business As Usual	2025 Targets	2030 Targets
Operational Energy kWh/m2/year	120	<60	<35

Figure 55 Whole life carbon targets (courtesy WSP)

Offsetting

Despite processes and the carbon hierarchy being followed, there is often a significant residual carbon impact that has to be addressed through carbon offsetting. This does not mean that offsetting can be used as a substitute for best practice sustainable construction and operation. Carbon offset means emission reductions or removals achieved by one entity can be used to compensate (offset) emissions from another entity. Carbon offset credit refers to the transferable instrument certified by government or independent certification bodies to represent an emission reduction of one metric tonne of CO_2 or CO_2e.[93] For any un-abatable residual emissions, investing in carbon reduction or storage projects is the secondary priority. The final opportunity is to 'advance tangible benefits' through directing funds into offsets that store carbon and provide further environmental and/or social improvements, particularly those that have additional nature-based co-benefits.[94]

The remaining carbon should be offset using a recognised offsetting framework and the number of offsets should be publicly disclosed.

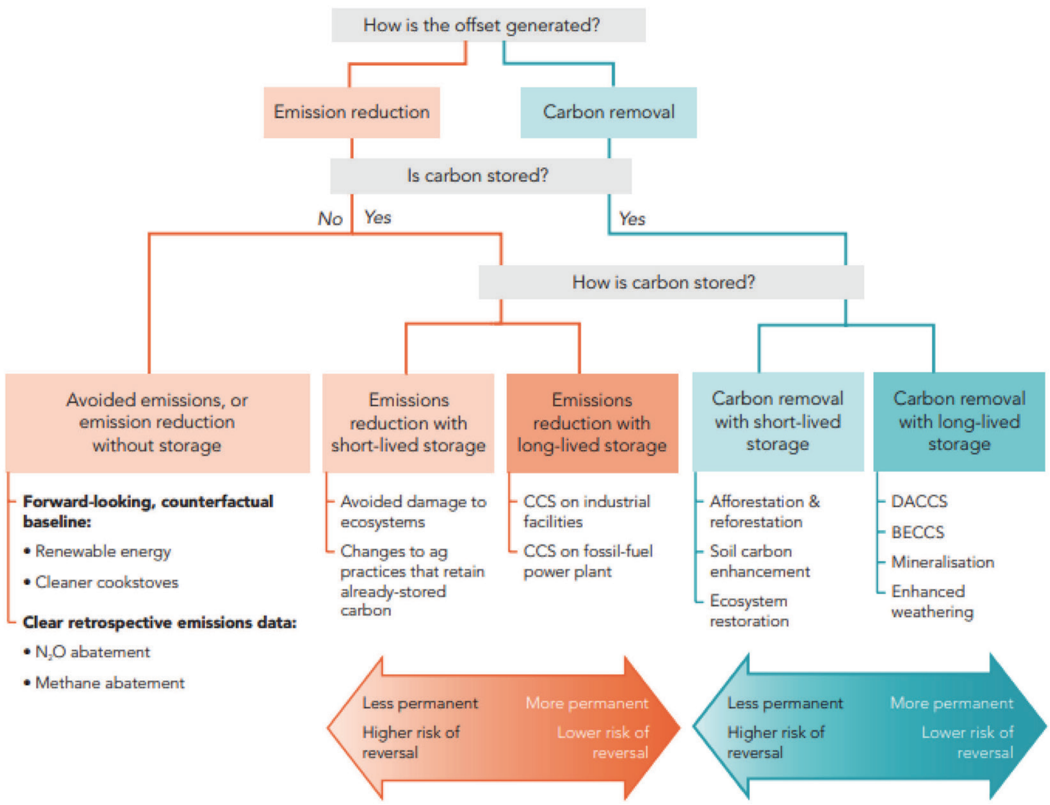

Figure 56 Renewable energy procurement and carbon offsetting (courtesy UKGBC)

Circular Economy and end of life

A Circular Economy is an alternative to a traditional linear economy (make, use and dispose) with the aim to:

- keep resources in use for as long as possible
- extract the maximum value from them while in use
- recover and regenerate products and materials at the end of each service life.

At the end of life:

- **Maintain** – care and maintenance that retains the building, system, component or material as fit for purpose to maximise its useful life.
- **Refurbish** – redevelop through restoring, refinishing and futureproofing while avoiding unnecessary major replacement of any parts. This also encompasses retrofitting.
- **Repurpose (with adaptation)** – redevelop with significant major changes and replacement of shorter-life parts to accommodate different needs and uses (eg from industrial to mixed-use).
- **Deconstruct and reuse** – deconstruct a building and retain its constituent elements, systems and components as much as possible. Reuse each system, component or material again through checks, cleaning and repair, and with minimal reprocessing or remanufacture. Ideally, further processing or transporting should be avoided where possible.
- **Remanufacture and recycle** – recycling is when materials at end of life are reprocessed and remanufactured into products, materials or substances whether for the original or alternative purposes. This incurs additional energy inputs and materials may devalue. The terms 'upcycling' and 'downcycling' describe when the recycling process shifts the value of the material or product higher or lower than the original.

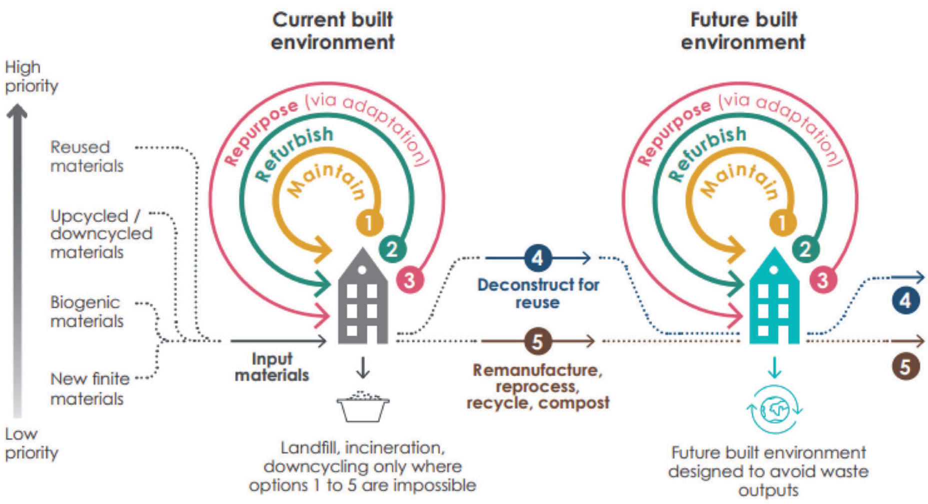

Figure 57 LETI's current vs future built environment

Abbreviations

AACM	Alkali-activated cementitious materials
ABM	Advanced building material
APQP	Advanced Product Quality Planning
BEIS	Department for Business, Energy and Industrial Strategy
BESA	Building Engineering Services Association
BIM	Building Information Modeling
BOPAS	Buildoffsite Property Assurance Scheme
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BSI	British Standards Institute
CDE	Common Data Environment
CDP	Contractor's design portion
CEN	European Committee for Standardization
CIH	Construction Innovation Hub
CLT	Cross-laminated timber
CPD	Continuing Professional Development
CQP	Construction Quality Process
DCO	Development Consent Order
DfA	Design for assembly
DfM	Design for manufacture
DfMA	Design for Manufacture and Assembly
DLUHC	Department for Levelling Up, Housing and Communities (formerly Ministry for Housing, Communities and Local Government, MHCLG)
EPSRC	Engineering and Physical Sciences Research Council
ESG	Environmental, social and governance
EUI	Energy Use Intensity (targets)
FEES	Fabric energy efficiency standard
GCP	Galvanic cathodic protection
GDP	Gross domestic product
GEN	General concrete
GGBS	Ground granulated blast-furnace slag
GHG	Greenhouse gas emissions
GIIG	Government and Industry Interoperability Group
GLT	Glued laminated timber
GPU	Graphics processing unit
GRC	Glass reinforced concrete

HSE	Health and Safety Executive
HVAC	Heating, ventilation, and air conditioning
ICCP	impressed current cathodic protection
ICCP	Impressed current cathodic protection
ICE	Institution of Civil Engineers
IMPACT	International measures of prevention, application and economics of corrosion technologies
IoT	Internet of Things
IP	Intellectual property
IPA	Infrastructure and Projects Authority
IStructE	Institution of Structural Engineers
ITT	Invitation to tender
LAN	Local area network
LETI	London Energy Transformation Initiative
LRQA	Lloyds Register Quality Assurance
LVL	Laminated veneer lumber
MAU	Modular anode unit
MEP	Mechanical, electrical and plumbing
MMC	Modern methods of construction
MTC	Manufacturing Technology Centre
MVHR	Mechanical Ventilation with Heat Recovery
NBS	National Building Specification
NCC	National Composite Centre
NHBC	National House Building Council
NHP	New Hospitals Programme
ORP	Open Regulation Platform
OSM	Offsite manufacture/manufacturing
PAN	Personal area network
PCSA	Pre-contract service agreement
PMV	Pre-manufactured value
R&D	Research and Development
RC	Reinforced concrete
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SCC	Social cost of carbon
SCM	Secondary cementitious material

SME	Small and medium-sized enterprises
ST	Standardised prescribed concrete
TfLP	Transport for London Property
UKGBC	UK Green Building Council
UKRI	UK Research & Innovation
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual reality
WAN	Wide area network
WOL	Web Ontology Language
WGBC	World Green Building Council
WIMES	Water Industry Mechanical and Electrical Specifications

Buildoffsite and CIRIA members

ABG Geosynthetics Ltd
Accolade Measurement Ltd
Action Sustainability
AECOM Ltd
Aliaxis
Arcadis
ARL Asbestos Ltd
Arup Group Ltd
Aston University
Atkins Consultants Limited
Autodesk Ltd
Balfour Beatty Group
BAM UK & Ireland
BSI
Building Understanding
BCP Council Bournemouth, Christchurch and Poole
BES Group Strainstall
Binnies UK Limited
BWB Consulting Ltd
City University of London
Civil-Tek Products Ltd
Costain Limited
COWI UK Ltd
Curtins Consulting
C-Probe Systems
Construction Specialities
Danfoss Ltd
Darcy Products Ltd
Donaldson Timber Systems
East West Rail Co Ltd
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Institution of Civil Engineers
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Kier Group plc
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London Underground Ltd
M10 Construction Ltd
Maccaferri Ltd
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Marshalls PLC
Mistras Group Ltd
Morgan Sindall Engineering Solutions
Mott MacDonald Group Ltd
National Highways
Network Rail
Northumbria University
Northumbrian Water Limited
Peabody Housing Trust (Thamesmead Team)
Premier Modular
Rail Safety and Standards Board
Roger Bullivant Ltd
Royal HaskoningDHV Ltd
SDS Limited
Sir Robert McAlpine Ltd
SLR Consulting Ltd
Southern Water Services Ltd
Stantec
Stuart Michael Associates
Screening Eagle UK Ltd
Stelling Modular
T&S Environmental Ltd
Temple Group Ltd
Tempo Housing
Thames Water Utilities Ltd
TOPCON (GB) Ltd
Transport Scotland
United Utilities Plc
University College London
University College of Estate Management
University of Birmingham
University of Cardiff
University of Greenwich
University of Hertfordshire
University of Reading
University of Southampton
University of the West of Scotland
Vision Modular Systems
WS Transportation
WSP
Zero Waste Scotland

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This guide aims to help clients and their advisors understand the benefits and how they can deploy modern methods of construction (MMC). It will be of particular use to those using offsite methods in their projects and programmes across their asset portfolios.

A range of subjects are considered from a strategic perspective, while providing many practical tips, guidance and case studies. It is designed to be complimentary to existing industry guidance and both national and international standards.

Infrastructure and the building aspects of construction, which may benefit from the advantages of offsite solutions, are discussed, including insights into the different categories of MMC. The guide addresses whole life cost and whole life carbon – including the social cost of carbon – with the future challenges of climate change in mind (Appendix 1). Guidance has been provided for project planners and specifiers, to facilitate project delivery using offsite methods and avoid unintentional outcomes of actions that may create barriers to adopting offsite construction.

Innovation across the construction sector is ongoing and this guide considers how intellectual property may be managed and new innovations brought to market, including details on assurance schemes.

Procurement processes are also evolving, which should facilitate the adoption of offsite solutions. More clients are requiring the delivery of digital twins for their facilities; this guide explains how inter-operable digital twins may add value and how offsite solutions can help.

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