The Forge – a 'Platform' approach in action.

Landsec, one of the UK's largest commercial property development and investment companies, has always been at the leading edge of tech-led design. Their ambition is to use innovation to deliver buildings faster, better, safer, greener, and more cost-effectively. This meant taking a tech-led approach at their flagship office development, The Forge, and conceiving the building as a product constructed from a 'kit of parts'.

As a result, they chose the platform approach, developed by architect and Design for Manufacture and Assembly (DfMA) specialist Bryden Wood, and described by the Infrastructure and Projects Authority (IPA) in 2018 as *'the design, procurement and construction of built assets use a defined set of standardised and interoperable components. These components should be designed to be manufactured efficiently at scale using repeatable processes.'*

In 2019 Landsec and Bryden Wood partnered with product prototype and development company Easi-Space to begin an R&D collaboration supported by UK Research and Innovation (UKRI) and its partner organisation Innovate UK. This collaboration would take the traditional office design and reconceive it using a tech enabled, platform (P-DfMA) 'kit of parts' approach. The Forge was selected by UKRI as a Demonstrator project for the industry and received Transforming Construction Challenge funding.

Although this design was initially developed for the Forge project, the intent was to use repeatable processes and components which could be used for future Landsec projects (encoding the design in digital tools) and by the wider industry (open sourcing all learnings via UKRI).

"*You have one of the UK's largest companies, working with one of the UK's smallest companies, and one of its most innovative design organisations, who have come together to produce something that, we hope, will start to change the way future buildings are designed, delivered and constructed*."
Neil Pennell, Head of Design Innovation and Property Solutions, Landsec

Government have continued to support and encourage the development of platform approaches, with the aim to mandate the approach outlined in the IPA's *Transforming Infrastructure Performance: Roadmap to 2030*. As a result, The Forge became a trailblazer project; taking this approach from theory to practice and sharing learning that could benefit industry by increasing ease of adoption.

"*The Forge is a landmark moment. With the Government platforms mandate imminent, we are seeing how the future of construction can and will be transformed*." Jaimie Johnston MBE, Bryden Wood

Having proved its value through the initial R&D prototype collaboration, The Forge became the world's first major commercial building to be designed and built using a platforms approach to design for manufacture and assembly (P-DfMA) and is due to complete this year. The design includes two new-build office buildings, set around a publicly accessible internal courtyard, in total comprising c. 139,000 sq. ft. of office space, with nine storeys, a reception and basement areas.

The process: design

Analyse, optimise, and rationalise

Bryden Wood took the initial site-specific design that had gained planning permission analysed it along with several other Landsec schemes at varying stages of design, plus commercial sector guidance documents published by the British Council of Offices to identify key areas of potential rationalisation and standardisation. A similar process is now described in the 'Harmonise, Digitise, Rationalise' policy in the Construction Playbook.

This led to a rationalisation of the design and the development of a highly repeatable kit of parts. A novel hybrid steel and concrete structural system based on platform design for manufacture and assembly (P-DfMA) principles was used for the regular 9m x 9m and 9m x 6m structural bays to create the superstructure. The standardised approach also benefited the design, manufacture and installation of the façade and mechanical and electrical services.

Around 20% of the building was constructed traditionally, for example the end bays adjacent to the perimeter and the double height ground floor; combining the platform with elements of bespoke design meant Landsec could mould the geometry of the buildings to maximise the footprint of the site, whilst remaining within the scope of the planning permission.

Cross sector application

The steel and concrete hybrid superstructure was based on the Ministry of Justice (MoJ) mid-span 'Platform 2'previously developed by Bryden Wood; taking the same components, temporary works, method of manufacture and assembly, but configuring the components differently and adding one additional beam type to the 'kit' to boost the spanning capability from 4.2m x 8m bays for an MoJ building to the 9m x 9m office grid.

1 MoJ Platform 2, with temporary works in place. ©Bryden Wood.

2 Landsec Platform, also with temporary works in place. ©Bryden Wood.

Digital design for future repeatability

The Bryden Wood team then used a combination of typical construction software (Revit, Tekla) and platform-specific routines (in Grasshopper and Dynamo) to automatically generate a data set describing the position and orientation of every structural component by drawing on a digital library of standard columns, beams, connections and so on.

This data set was then used to create a complete bill of materials for pricing and procurement, as well as automatically generating the Building Information Model (BIM) for coordination with the traditional-build elements, façade and mechanical and electrical (M&E) services models, i.e. the BIM model was one 'view' of the central data set and not the only data set for the project.

The data set also generated QR codes to identify individual components, so the construction team could track components from the factory through to final installation.

Cyclical learning: iterating to optimise

Creating the design digitally meant that changes and optimisations from stakeholder or prototyping learnings, could be inputted, with connected elements automatically updated (this process took less than an hour to run). The data set, and geometry from SolidWorks models of individual components, could then be sent to fabricators to manufacture the components to precise dimensions and specifications.

With the repeatable components embedded in the design, the team could then focus more time on the elements that had to be bespoke to the site and the buildings.

Prototyping to manage risk and ensure efficiency.

Given the huge quantity required of each component when building at scale, time and effort was invested in designing and optimising every component for efficiency and ease of assembly.

However, as is the case in general manufacturing, prototyping was critical to pressure test the design. A prototype of the novel hybrid steel and concrete superstructure was built at the Construction Research Platforms Centre, a facility in Ropley, Dorset, developed jointly by Bryden Wood and Easi-space.

The prototype proved the conceptual design was deliverable and made sure that all aspects could be assembled as efficiently, productively, and safely as possible; significantly reducing the risk involved.

3 M&E installation being tested on the prototype. ©Bryden Wood.

The prototype served several purposes providing a test bid for the use of mobile lifting equipment, integrated handrails, and M&E cassette assembly installation methods.

Delivery embedded in the design: not just what you build, but how you build it

The project's innovation was as much in its construction methodology as it was in its component methodology.

To be truly successful, the 'kit of parts' needs to dovetail into a more efficient construction process; one that is more predictable and garners a higher quality more quickly.

The design of the superstructure was taken to a higher level of completion at an early stage with input from the supply chain partners and construction managers. This enabled manufacturing efficiencies and the installation process to be built-into design of the key components following the design for manufacture and assembly methodology. The superstructure design and the temporary works elements used to construct it were highly rationalised for repeatability, so the structural bays followed a standardised pattern, with repeated fixing points for the external cladding at the perimeter and for the high-level on-floor M&E services assemblies across the floor plate.

An 'adapter frame' was developed to create the standardised bays - the single frame was then designed with accurate, embedded interfaces, to which everything else could be easily fitted: cladding panels, pipework, fancoil units etc. These frames then streamlined the manufacturing, logistics and assembly process.

Fixing points were pre-cast into the soffit for the later M&E installations: the standard nature of the adapter frame gave an accuracy that enabled the team to pre-cast fixing points to avoid drilling into the soffit onsite – avoiding working at height, dirt, noise, and the risk of drilling into rebar within the concrete. A total of 23,500 fixing points were created in this way, creating significant benefits in terms of safety, productivity, and quality.

As such The Forge superstructure became an enabler of factory like assembly conditions in the construction process.

Factory-like conditions in the construction stage

The intent of this approach is to reimagine the site as a factory environment. The pre-cast fixings in the superstructure for the M&E services installations were replicated for the elevator installations using inserts cast into the twinwall product used to construct the lift shafts. QR coded components were delivered to site in wheeled stillages which were used to move material quickly to the workface where a variety of mechanical lifting devices were then used to place them in position.

TIP 2 states "*Platform approaches deliver via a series of simple, repeatable, productive activities. This addresses challenges presented by the size of the build and enables predictability in the sequence of work*"

Temporary works

The temporary works elements were rationalised and used repeatably to create efficiencies. All the floors were built using one set of shutters and two sets of props. The slab above was installed from the slab below using the shutters and first set of props. The shutters were then quickly struck cleaned and moved up to the next floor where they were used with the second set of props. The first set of props were then released and the cycle repeated minimising the amount of temporary works material (which is also all re-usable or recyclable).

The superstructure

A secondary structural beam was formed using a permanent steel shutter comprising a section of ComFlor (a Tata Steel metal floor product) containing steel rebar reinforcement. The 'ComFlor beam' was then lifted into position using a reach stacker, a highly versatile lifting machine with three-dimensional adjustment capability commonly used in the warehouse sector which was repurposed for construction use on the project.

The intention behind using mobile lifters was to reduce reliance on the use of the tower cranes which would be relatively inefficient to use for this assembly task and whose operation is susceptible to high winds. The ComFlor beams are then slotted into dedicated sections of the primary beams at 3m centres.

Shutter tables, pre-fitted with rebar, were lifted into the space between the ComFlor beams and fixed to temporary support bars under the beams. Self-compacting concrete was then poured over completed shutter system to create the slab and fill the ComFlor beams.

The temporary works assembly system with its distinctive diagonal propping transferring load directly into the primary steel structure without the need for vertical back propping from the slab below was key to the effectiveness of the platform structure.

This allowed work to continue on the floor above as soon as the concrete had set, without having to wait for it to cure to its final strength level. This meant that within 24 hours of casting the slab, construction of the next level could begin.

The systemised approach also improved the sustainability of the structure. With the curing time not being a constraint on the floor cycle time it was possible to reduce the cement content of the concrete and use a higher proportion of granulated ground blast furnace slag (GGBS) in the mix, significantly reducing its embodied carbon level.

"*It's fair to say there was a very ambitious cycle time of 15 days per floor and we did achieve that – but it took quite a lot of learning to get there*." Angela Branch, project director for Sir Robert McAlpine.

Mechanical and electrical (M&E) installations

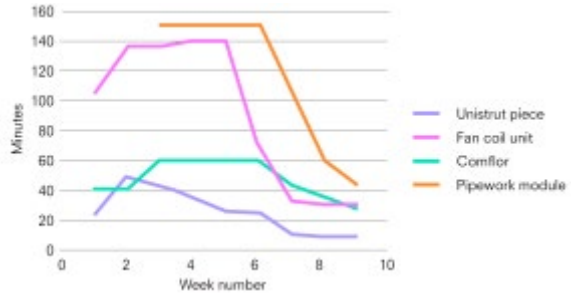
The on-floor M&E challenge was to integrate the high-level services installations with the superstructure in a way that would maximise the clear height on the office floors and be an aesthetically appealing, high quality installation that would be attractive to perspective occupiers.

This was achieved by rationalising the design to enable it to be broken down into small number of repeatable pre-assembled multi-service modules:

NG Bailey, who have been at the forefront of the use of offsite manufacturing techniques for M&E services installations since the 1990s, were appointed to manufacture and install the pre-assembled modules. Production took place at their specialist facility in Bradford where innovative manufacturing and assembly processes were used to create a series of standardised cassette-based modules mounted on small lightweight carrier frames. Pre-jigged benches were set up so that the M&E component assemblies could be mounted on the frames incredibly quickly.

- Completed cassette assemblies are stacked vertically on a purpose designed stillage using spacer bars to keep them apart
- Each rack contains between four and six modules (depending on the type of equipment in the assembly) mounted on a wheeled base for ease of handling
- The racked modules are loaded onto lorry transports and delivered to site
- On arriving at site, the racks are unloaded and transferred to large material hoists which deliver them to the floors
- Racks are wheeled across the floorplates and then lifted up to the soffit using specially adapted lightweight forklift trucks (when they became available – initially Genie lifts were used) and then fixed into position using the cast in fixings
- The spacer bars are removed, and the process repeated until the rack is empty
- The wheeled base and spacer bars are returned to the factory to be re-used with the next set of cassette modules destined for site

4 M&E racks, being delivered to site and installed. ©Bryden Wood.



5 M&E cassette installation times, showing how times reduced as the team moved from Genie lifts in week 5 to the specially adapted forklifts. ©Bryden Wood.

6 Floorplate with M&E cassettes fitted in position (note fan coil unit rack on its wheeled base in the foreground). ©Bryden Wood. Photography by Jocelyn Low.

Mark Griffin, Offsite Integration Manager at NG Bailey said: *"A key success of the early DfMA integration on this project allowed the MMC methodology to be maximised and improved for both the manufacture and installation sequences. It has also provided a wealth of accurate data for the offsite manufacture and the onsite installation programmes. We've also really drilled down into the data to capture the information we need to clearly demonstrate the benefits this approach delivers."*

The approach has removed circa 20,000 operative hours from the project and delivered substantial carbon benefits by avoiding 35,600km of vehicle movements, which saves six tonnes of carbon alone.

Façade

Separate contracts were awarded for the manufacture and installation of the facade.

Integrated reusable safety handrails were designed to be installed pre-attached to the perimeter superstructure components – with the ability to leave them in place until the façade was in position.

This both reduced danger to operatives on site and helped with the ease of installation of the perimeter columns and façade panels.

7 South and West façade elevation nearing completion (Bronze building). ©Bryden Wood. Photography by Jocelyn Low.

The perimeter structure comprised a series of micro-columns positioned at 3.0m centres to reduce slab deflection and provide an accurate frame for the cladding panels to fix onto. Primary fixing brackets on each column which can be accessed through the safety handrails provide a quick and efficient means to attach the cladding panels to the frame.

At peak productivity one panel was installed every seven and a half minutes.

The process: project management

The Forge was managed using a new, collaborative project process:

- Across disciplines - a range of skills working together and sharing knowledge

- Within industry - working closely the supply chain from an early stage, the inter-industry collaboration was critical to the delivery process
- Digitally - the team used technology collaboratively, visualising data to make it easy to understand and use

Across disciplines

Combining the sector knowledge of Landsec with architects, computational designers, civil, structural and M&E engineers and industrial designers from Bryden Wood, the prototyping and procurement capability of Easi-Space, construction management expertise from Sir Robert McAlpine and Mace, and the support of specialist supply chain partners, the project was able to turn new ideas into on-site reality.

Within Industry

The project adopted a Construction Management (CM) approach which enabled closer relationships with the supply chain from an early stage in the project.

To reflect the focus on DfMA the construction management role was redefined as 'Manufacturing Assembly Manager' (MAM) and a joint venture company formed by leading contractors Sir Robert McAlpine and Mace was appointed at RIBA Stage 3 to deliver the project.

Pre-construction services agreements (PCSAs) were used for certain packages (M&E, air package, sprinklers, facades, steelwork, and lifts) to engage manufacturers to help inform and optimise the design at early stages. In some instances, the supply and installation works within a package were procured separately to ensure best value e.g., the façade was split into manufacture (Aluprof) and assembly (NACWL) portions.

Using this approach the client and design team were able to engage with the supply chain at an early stage allowing them to contribute their expertise to the development of the design and optimise the manufacturing and installation processes.

"*For us the collaboration brought the disciplines of a large organisation and the efficiency of a small business together and resulted in some valuable and impressive results in a short time frame*"
Kieran Coe, Founder, Easi-Space

Digital

To facilitate interactions across a large number of participants – from designers to manufacturers from purchasers to installers – the components were defined digitally, and Bryden Wood created a comprehensive digital component library that included all related data, from material specification to cost. This library in turn enabled the shared digital ecosystem that all parties could access.

Project achievements

Although the full extent of the transformation that platforms are capable of is still some way off, The Forge has already seen many benefits from its innovative approach:

Net zero

It is the UK's first commercial building to be endorsed by the UK Green Building Council's as meeting its framework definition of a net zero carbon building in both construction and operation. This has been achieved using a combination of energy efficiency measures, resource efficient lean design and manufacturing methodologies including:

- Replacement of traditional gas boilers and chillers with roof-mounted air-source heat pumps
- Roof mounted PV panels
- Rainwater harvesting and green roof areas
- Reducing the basement area by 53% and volume by 70%, equating to a reduction in substructure carbon of 40% compared with the original design
- Creating a reusable set of temporary works components
- Minimising cement use - 50% ground granulated blast furnace slag (GGBS) used in the substructure concrete and 40% in the floor slabs
- Using less materials to reduce the embodied carbon of the structure - 18.4% less steel and 13% less concrete compared with benchmark measures
  Reduced waste from offsite manufacturing and use of reusable stillages to transport components and pre-assemblies

Safer

Reduced working at height. Built in fixings for M&E modules and lifts reducing the need for manual drilling. Integrated handrail system providing a safe workspace enclosure as the structure is erected minimising the need to work at exposed edges to fix perimeter steelwork and cladding panels. Automated construction processes using mobile lifting equipment to minimise manual handling for the DfMA packages.

Retains creative freedom

The kit of parts was designed to offer choices in how the parts are put together. The platform design delivered the original architectural design that gained planning permission for the development, whilst leaving flexibility for the platform components to deliver against an entirely different architectural vision on future projects.

More efficient

The design has demonstrated that a platform approach can work well with a 3.5m slab to slab height delivering a clear height of 2.75m with an exposed structure. With typical slab to slab heights of 3.8 - 4.0m for more traditional office structural designs this could result in an additional floor for every 7 – 12 storeys within a given planning height envelope.

Higher productivity

The project team is working closely with specialist researchers from the University of Cambridge Department of Engineering to analyse data collected from site to understand the potential gains in productivity that can be achieved from the combination of DfMA processes, automated construction methods and data-based decision making.

Lessons learned for the future

The Forge is due to complete later this year. It has shown that the platforms approach to construction requires some getting used to - as with all new innovation. However, it has also demonstrated that the platform approach works as the theory intended and has the potential to fundamentally transform how we design, procure, manufacture and construct buildings.

Some of the learnings that we and the industry can take forward from this first-time use of a P-DfMA led solution include:

- No building will ever be rationalised or standardised entirely – this means that platform components built to manufactured tolerances will have to interface with elements of traditional build that are installed to much greater tolerances.
- This project has revealed the need to plan for appropriate flexibility in the system to accommodate the variability of these interfaces at the design stage
- Further work is needed to improve on and offsite quality control processes to solve the challenge of constructing to tighter tolerances going forward
- The management of construction logistics will need to evolve to deliver the full potential of P-DfMA:
    - The platform approach creates a process of pre-planned, simple and linked activities which rely on fully integrated workflows and a supply of components that need to be matched to the productivity levels being achieved onsite
    - Incredible bursts of productivity were achieved on the project when there was clear access to the workface, the required labour resource was applied, and components were readily available - but this couldn't be sustained over extended periods due to restrictions in the logistical supply chain
    - Achieving consistent productivity gains will rely on flexible 'Just in Time' supply and logistics solutions linked to real-time onsite monitoring systems
- A new approach to managing the transfer of construction risk is critical – we need to reduce, manage and share risk appropriately, and ensure that any residual risk sits with the organisation best placed to manage it
- The interrelationship and interdependency between packages needs to be better defined and understood, and more sophisticated collaborative working models need to be evolved to optimise the whole process of construction and incentivise behaviours:
    - In construction some measures within a package may not be of direct benefit to that particular installer but will improve the productivity of later packages.
    - The building superstructure is a good example of this as it provides the carrier frame for the cladding, services and fitout installations
- New collaborative and incentivised commercial models need to be explored to balance risk and reward and enable early supply chain involvement in the design and logistics planning processes
- Defining the commercial model(s) will be critical to increase client confidence and adoption of this new approach to construction.