Measuring Construction Site Productivity
A seven-step framework for success

May 2022

Contents

Executive summary

Construction site productivity is the rate at which a building or construction activity is being completed. It is a measure of efficiency of production and is defined as the ratio between the output of work completed and the input of resources used.

The construction industry's average productivity levels have remained consistently below the UK average. In real terms, gross value added (an economic productivity metric for the value created by an entity engaged in the production of goods or services) increased by just 12% in the 22 years to 2019 (less than 0.5% per year on average), compared with the whole UK economy which saw a 53% increase (more than 2.0% per year on average), according to Mckinsey & Company[1].

The Construction Productivity Taskforce has produced this framework to provide practical guidance for how a construction site productivity improvement programme can be planned, developed, and implemented. It shows how data captured from onsite activities can be used to identify productivity improving insights which can be actioned on active projects and inform future practice.

The framework should be read in conjunction with the Private Sector Construction Playbook, also produced by the Taskforce, which seeks to drive transformation in the construction sector to achieve better outcomes across a range of industry measures including productivity through the adoption of collaborative teams, long term engagement across projects, standardisation and modern methods of construction, risk sharing contracts, and investment in a strong supply chain.

The framework proposed, known as the 'Data-to-Dashboard'[2] strategy, draws on the learnings gained from implementing this framework on two live UK pilot projects, that were under construction at the time this document was produced.

The work on the pilot projects, some of which is showcased in the case studies included in this document, has demonstrated the effectiveness of using the framework to collect data and identify insights into how to improve site productivity.

One of the pilot projects uses traditional construction techniques and the other a Platform Design for Manufacture and Assembly (P-DfMA) methodology using modern methods of construction (MMC) illustrating the benefit of the framework irrespective of the construction approach adopted.

[1] Reinventing Construction: A Route to Higher Productivity, McKinsey & Company, February 2017
[2] Murguia, D., Chen, Q., Jansen van Vuuren, T. Rathnayake, A., Vilde, V., Middleton, C. (2022) Digital Measurement of Construction Performance: Data-to-dashboard strategy. Proceedings of the 22nd CIB World Building Congress. Melbourne, Australia, 1-10.

Our findings from the pilot projects, suggest that construction site productivity can be significantly improved through:

- Increased offsite manufacture and standardised design solutions
- Increased automation of the building process
- Targeted and considered use of digital technologies
- Improved collaborative activity planning and logistics management
- Improved training and upskilling of the workforce
- Reduced waste

By applying the guidance and recommendations outlined in this framework, users will better identify where productivity improvements can be made across a construction site, work package or task. A data driven programme can then be developed to implement productivity enhancing measures.

We want this framework to be a key management tool that is used on construction sites across the country. It has an explicit focus on why, what, and how to measure construction site productivity, complete with recommendations and observations that, if followed can generate productivity enhancing actionable insights.

Going forward, the Taskforce is continuing the work on the pilot projects to test and evaluate further productivity metrics. We also plan to expand our focus areas to other drivers of productivity including, but not limited to, designing for productivity and training for productivity.

This framework is designed to be put to work, in service of a higher performing sector. In the future, as we all strive to deliver better and more productive projects, we hope to see the framework continue to evolve as a living document which is constantly updated as further learning and evidence is gathered from projects adopting this approach.

Definitions

The Construction Productivity Taskforce

The Construction Productivity Taskforce brings together leading figures in the construction industry – clients, contractors, supply chain and designers – to undertake practical interventions designed to improve productivity in construction. Its initial ambitious scope of work focusses on three mutually reinforcing areas, designed to improve performance.

- **Data and metrics** – defining a set of productivity and waste metrics which can drive performance improvement and, facilitating clear and consistent data, drive a performance culture which enables a step-change in industry productivity

- **Collaborative contracting** – creating a 'Private Sector Construction Playbook', mirroring the Governments Construction Playbook published in December 2020, but tailored to the private sector, prioritising increased productivity

- **Pilot projects** – testing productivity measurement and improved ways of working across two live construction sites, to identify insights to improve productivity, and develop a productivity framework to share with industry: *Measuring Construction Site Productivity: A seven-step framework for success*

Output and learning from the Taskforce will be shared throughout the industry to increase the diffusion of best practice – identified by Be the Business, the Bank of England, and others, as critical to boosting UK productivity[3].

Key outputs from the first two focus areas are the Taskforce's support for the launch of the Construction Data Trust and the creation of the Private Sector Playbook.

This framework is the key output from the third focus area, the pilot projects.

Members of the Taskforce include British Land, Bryden Wood, Cast Consultancy, GPE, Landsec, Lendlease, Mace Group, Morrisroe, Sir Robert McAlpine, Skanska, and SOM.

[3] The UK's Productivity Problem: Hub No Spokes (bankofengland.co.uk)

The Construction Data Trust

The not-for-profit Construction Data Trust (CDT) was founded in 2020 and is committed to transforming how construction projects are delivered.

It enables a data-driven approach to resolving construction sector challenges, which includes productivity, health and safety, and sustainability.

The Trust manages a data platform to securely pool construction data from multiple sources to create a critical mass that can be analysed to create insights, that would be impossible for individual organisations to do themselves.

It performs three key roles:

- Legal steward of data managed by the Trust
- Data steward to establish a productivity data pool from current and completed projects
- Undertaking project work to assist in collecting and analysing data, establishing productivity benchmark metrics and consistent measurement rules

The Trust is a membership organisation, enabling members to collaborate on solving common problems, prioritising how and for what purpose members' data will be used to generate greatest benefit to the construction sector.

If you are interested in becoming a member of the Trust or supporting its work, please visit: www.datatrust.construction

The Private Sector Construction Playbook

This Playbook, produced by the Construction Productivity Taskforce, sets out key policies and guidance showing how the transformation of the sector can improve the delivery of construction projects – in a way that is collaborative across the industry driving productivity, value, building safety and sustainability, and protecting the health, safety and wellbeing of the people engaged in it.

It is for the building and construction sector – to drive successful projects through effective partnerships, innovation, and collaborative contracting

It is designed to support everyone involved in the construction process – from clients to contractors, from designers to construction managers, from bid writers to procurement teams, from logistics specialists to supply chain suppliers and beyond.

The Playbook takes inspiration from the Government's Construction Playbook document published in December 2020 and has adapted it for the private sector.

It shares many of the high-level aspirations of the Public Sector Playbook but reflects the wider range of organisations and projects involved in the commercial sector, narrowing the focus in some areas and introducing new measures of success, including maximising economic, environmental, and social value.

The playbook was produced with contributions from across the project spectrum with input from contractors, clients, consultants, and SMEs.

Foreword

Katy Dowding

Construction Productivity Taskforce and pilot project sponsor. Executive Vice President, Skanska

The Nobel Laureate in Economics, Paul Krugman said, "Productivity isn't everything, but in the long run, it's almost everything." Higher productivity is what drives higher profitability for business and wages for workers. In a construction context, that means projects being built more quickly, affordably, and safely, with a lower environmental impact.

Charting a more productive course for the sector cannot afford to wait. UK productivity has stagnated for over a decade. At the same time, challenges such as an aging workforce and competition for talent have competed with external factors including Brexit and the Covid pandemic for the attention of business leaders in every sector.

But the construction sector has opportunities to improve adoption of management best practice and technology, including automation that are proven to boost performance.

This ambition is what brought members of the Construction Productivity Taskforce together in 2020. These leading industry figures have come together with the support of not for profit, Be the Business to undertake practical interventions designed to make the sector more productive.

We have three initial pillars of activity:

- Collecting productivity and waste metrics to inform better decision making throughout the construction process
- Improving the contracting process through a private sector playbook that builds on work already carried out in the public sector
- Trialling methods of improving productivity on working construction sites across the UK

This framework is designed to support the first and third pillars of this work and provide practical guidance into how a productivity improvement programme can be planned, developed, and implemented on a construction project. It is only by effectively measuring performance that you can identify where opportunities or challenges reside.

The work on the pilot projects which is showcased in the case studies has proven that using this framework enables you to collect data and identify insights into how you can improve site productivity, regardless of whether your project is traditional or utilises modern methods of construction.

Members of the Taskforce want this to be a tool that is actively used on sites across the country. It has an explicit focus on why, what, and how to measure productivity in a construction context.

We provide a seven-step framework, complete with recommendations and observations that, if followed can generate information that identifies pain points, and prompts better choices.

Like all the Taskforce outputs, this framework is designed not to sit in desk drawers, but to be put to work, in service of a higher performing sector. It is also an industry first, and while we strive for right first time on our sites, we hope to see further editions of this document produced as the industry evolves and we gather evidence from our sites.

Finally I would like to thank all of the members of the Taskforce for their openness and collaboration, without which the document would not have been possible. We see this document as not the final solution, but an important first step on the way to developing more effective ways of measuring and improving productivity.

Why are we producing this framework?

We are producing this framework to provide practical guidance into how a productivity improvement programme can be planned, developed, and implemented on a construction site. We'll show you how the data captured can be used to identify productivity improving insights – and so drive productivity improvements across the project.

Our framework can establish industry-wide productivity benchmarks or create productivity improvement studies across individual construction sites, work packages or specific construction tasks.

Our methodology draws on the learning and good practice gained from the productivity study work on two live UK pilot projects, that were under construction at the time this framework was produced and supports the policies and guidance for how collaborative contracting can be improved, as set out in the Taskforce's Private Sector Construction Playbook.

By applying our guidance and recommendations we outline here, you will better identify where productivity improvements can be made across your construction site, work package or task.

You can then devise a data driven programme to implement productivity enhancing measures.

The benefits of using this framework

What do we mean by productivity and why is it important?

It is important to distinguish productivity from production, as they are very closely related.

Construction site productivity is the rate at which a building or construction activity is being completed. It is a measure of efficiency of production and is defined as the ratio between the output of work completed and the input of resources.

Production is the process of producing buildings or goods from raw materials. It determines the outputs from the production process (e.g., volume or area of materials placed) and provides the data with which productivity can be measured.

For example, production determines the number of produced units, whereas productivity measures the efficiency at which those units were produced (as the ratio of outputs to inputs used). In short, the efficiency of production is the productivity of an organisation.

Across our industry there's a multitude of factors that impede improved productivity. These include non-availability of materials, inadequate workforce supervision and logistics, skill shortage, lack of proper tools and equipment and incomplete design information and specifications.

How can we improve current productivity?

There are many ways that construction site productivity can be improved. Our findings from the pilot projects, suggest that construction site productivity can be significantly improved through:

- Increased offsite manufacture and standardised design solutions
- Increased automation of the building process
- Targeted and considered use of digital technologies
- Improved collaborative activity planning and logistics management
- Improved training and upskilling of the workforce
- Reduced waste
- Early engagement of the design team with the specialist contractors to review the developing design and identify buildability improvements and productivity enhancing solutions

Before we can improve productivity in construction, we must first understand how to measure it. Construction productivity can be measured at:

The macro scale

Industry benchmarks – output achieved for the sector. This is typically measured as monetary value generated by the completed work (£) per the total man-hours to complete that work (hr)

The micro scale

Site-specific metrics – output achieved for a specific project, work package or activity. This can be a defined amount of work (m2 of floor area) completed per the total man-hours to complete that work (hr)

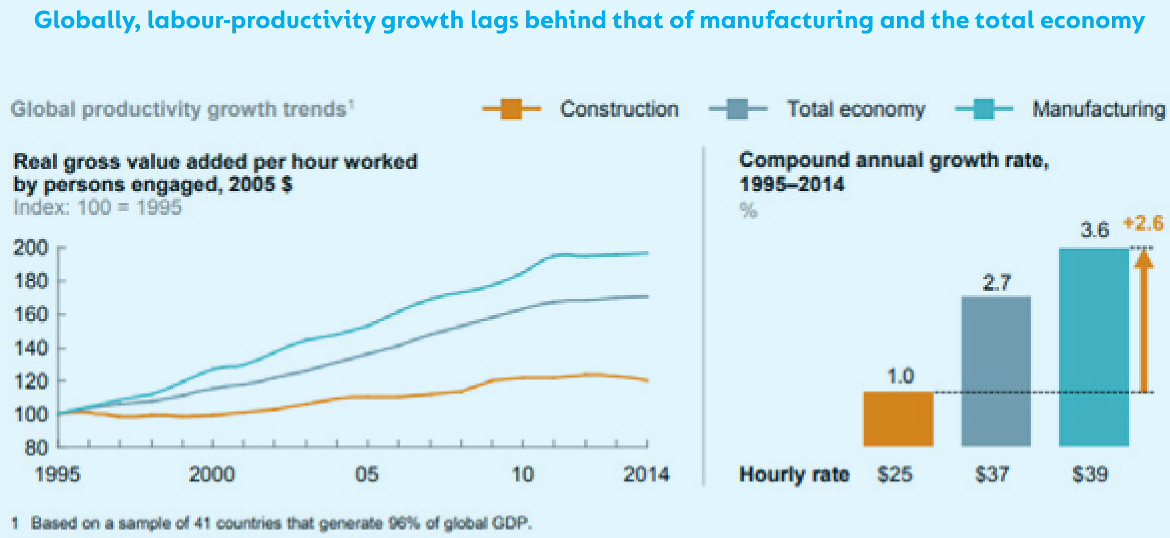
For both macro and micro scale productivity, the resulting measurements will depend on the project type, design, size, and location, and site-specific constraints. These factors must be considered when comparing one project with another.

It is clear we have a significant productivity challenge

The construction industry's average productivity levels have remained consistently below the UK average. In real terms, gross value added increased by just 12% in the 22 years to 2019 (less than 0.5% per year on average), compared with the whole economy which saw a 53% increase (more than 2.0% per year on average) as illustrated in Figure 1[4].

FIGURE 1

Comparison of global labour productivity growth 1995 – 2014 (Source: McKinsey Reinventing Construction 2017)



[4] Reinventing Construction: A Route to Higher Productivity, McKinsey & Company, February 2017

This, in part, reflects the larger fall in construction output during the 2008–2009 recession than for the economy overall. Since 2008, labour productivity has grown slightly faster than the economy but as shown in Figure 2 remains below the UK average.

Furthermore, there is no agreed framework or methodology for measuring productivity in UK construction, even though such a methodology is needed to help drive productivity improvement across the sector to remain competitive internationally and to improve the UK's standing across the globe. The development of an industry wide productivity measurement framework is a key aim of the Construction Productivity Taskforce, to stimulate wider productivity measurement across the industry using a core of agreed metrics.

There are significant benefits to boosting construction productivity

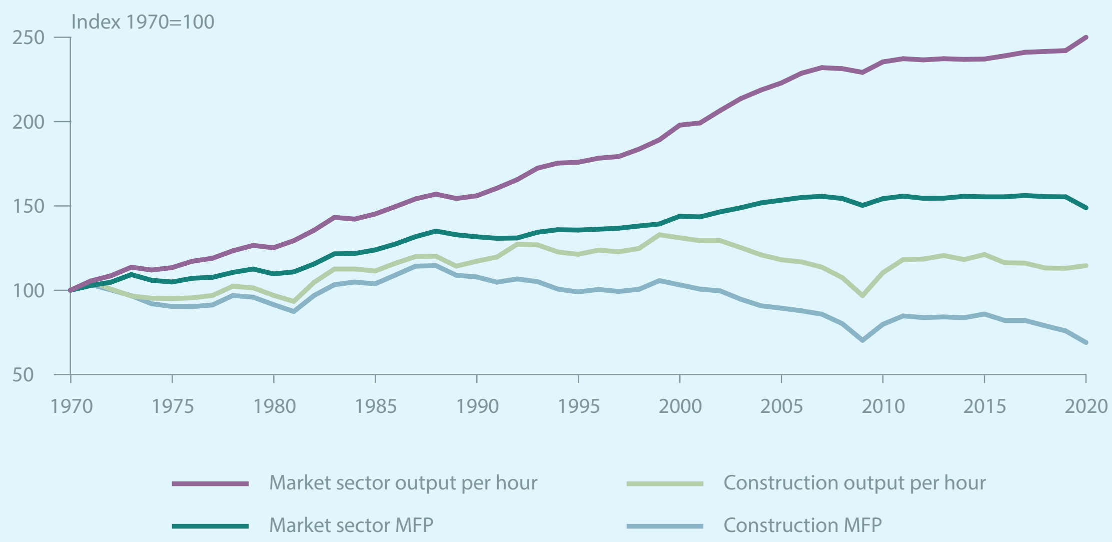
At a national level, productivity growth is important, and if successfully improved, creates multiple benefits that are distributed in several ways to:

- Workers, through better wages and conditions
- Shareholders and pension funds, through increased profits and dividend distributions
- Customers, through lower prices
- The environment, through more stringent environmental protection
- Governments, through increases in tax payments (which can be used to fund social and environmental programmes)

FIGURE 2
Productivity has changed little in the construction industry in the past 50 years

Output per hour worked and multi-factor productivity, construction industry and market sector, UK, 1970 to 2020

Multi-Factor Productivity (MFP) is the unexplained growth in output after accounting for growth in capital and labour inputs.



Construction benefits from our pilot projects

By widespread use of this framework across construction sites, significant productivity benefits can be realised across the whole project supply chain:

- Delivering shorter programmes, increased cost certainty without compromising quality and safety performance
- A drive for more efficient ways of working using more offsite manufacturing solutions and automated construction processes, such as Design for Manufacture and Assembly (DfMA) and Modern Methods of Construction (MMC)
- Facilitating early supply chain engagement in the design and construction planning process to allow the input of specialist manufacturing knowledge and experience
- Greater programme certainty – enabling faster programmes – thus allowing buildings to be completed and occupied faster, which will allow better commitment to completion dates for tenant occupancy
- A reduction in overall project preliminaries costs through more efficient working – enabling money to be spent on adding further value to the out-turn building product
- Achieving right-first time outcomes – a reduction in snagging/rework/latent defects and material waste
- A reduction in the operational carbon and energy of an operational construction site
- Mitigating disruptors that can impact site productivity – such as waiting time, late design, weather, rework, late/early deliveries, and labour and material supply shortages
- Better communication of design information, so that it's appropriately complete at the point of issue, reducing the need for clarifications, etc.
- A more efficient and safer site – promoting improved well-being for all project and staff

Clients' specific benefits

"Improving productivity is the key to driving transformational change in the construction sector. Higher productivity reduces costs, increases production, and enables the most effective use of available resources which is at the heart of sustainable construction. To be able to improve it is important first to measure and compare. This framework with its data to dashboard focus provides a great starting point for the industry to begin to standardise the process of measuring site construction productivity."

Neil Pennell
Head of Design Innovation & Property Solutions
Landsec

Main Contractors benefits

"The framework is an excellent demonstration in how, by working together, we can make our industry more efficient and productive, to deliver better outcomes more consistently across all projects. Promoting the key principles of collaboration with supply chain partners, increased application of smart construction techniques and the effective use of digital and data, the framework sets out an approach that will ensure consistency across the construction sector, while still encouraging solutions to be tailored to the individual project at hand."

Mark Reynolds
Group Chair & Chief Executive
Mace

Supply Chain/SME's benefits

"Understanding the efficiency of productivity levels on our sites will help those of us in the Supply Chain to improve our performance. This framework sets out in its seven-step process a practical means of measuring output, understanding the influences impacting our progress and suggests the adoption of interventions designed to get us back on track. The benefits of improving productivity from providing better value to our clients and enabling better pay and conditions to our workforce are obvious. This framework will help us to move the dial on productivity in the right direction."

Brian Morrisroe
Chief Executive Officer and Founder
Morrisroe

Designer's benefits

"As designers, we have the opportunity to work with clients, contractors and the supply chain to set the course for a project as it develops through procurement and construction, to operation and end of life. When we look to address the multiple and complex challenges facing our sector, and society more broadly, productivity connects them all. This framework will help establish a common understanding of how we define, measure and drive productivity; an important step in helping designers (and others) focus their energies effectively to deliver the increases in productivity we badly need."

Jaimie Johnston MBE
Director and Head of Global Systems
Bryden Wood

What should we measure?

A robust construction site productivity study should combine high-level benchmarking metrics and site-specific metrics, to obtain the most benefit and improvement from the study:

- **Benchmarking metrics (macro-scale):** can be used to establish project and industry-wide productivity benchmarks, and can be applied at project, work package and activity level
- **Site-specific metrics (micro-scale):** developed specifically for a construction site to enable specific productivity disruptors/opportunities to be identified and productivity insights highlighted and implemented

The power and potential of benchmarking metrics

The Taskforce have identified five high level benchmark metrics; **productivity, waste generated, pre-manufactured value, right first time** and **tool time** which they believe will help the industry to establish a quantifiable baseline which can then be used to drive the transformational improvements needed in construction productivity.

The benchmark definitions are summarised in **Table 1** on page 16.

These metrics were selected following a series of workshops where the aim was to identify measures that would have the following attributes:

- High relevance to productivity improvement
- Established performance measures already familiar to the industry
- Easy to measure and capture the data
- Relevant across sectors outside construction

TABLE 1
Construction Productivity Taskforce high level productivity metrics

Metric	What is it?	How to measure it?	Unit of measure	Reference
Productivity	The efficiency at which a building is being constructed, looking at the ratio of capital cost to man hours worked on site.	Value of work in £ excluding non-construction costs/ number of hours worked	£/hr	Construction Leadership Council
Waste generated	The ratio of the volume of waste that has been generated in the construction phase of building for every £100K of the capital cost.	Volume of construction waste (m3)/£100k project value. (NB – can also be measured in tonnes of waste, either directly or using the specific volume of the waste material)	m3/£100k or tonnes/£100k	Construction Leadership Council
Pre-manufactured value (PMV)	The proportion of the building cost of work that is being manufactured, preassembled, or constructed away from site.	Gross capital cost – site preliminaries – site labour cost)/gross capital cost	%	Construction Leadership Council Cast
Right first time	The proportion of rework required as part of the overall construction process. A measure of the cost of errors in the process.	Cost of rework in £/ Gross capital cost in £	%	This is a measure used widely in the manufacturing sector to measure rework cost.
Tool time	The proportion of time spent doing productive work on a building (not including waiting for parts, tools, instructions or travelling).	Time spent doing productive work/total time on site	%	This is a measure used widely in the manufacturing sector to measure time spent doing productive work

The Taskforce has also supported the establishment of The Construction Data Trust (CDT) which provides a platform for the industry to share anonymised performance related project data to help unlock cost effective innovation and establish industry wide comparison benchmarks starting with these five metrics.

The key to improving productivity at task, project and industry level is the identification of actionable insights from the data.

We believe that the combination of a consistent approach to measurement and access to open-source reliable comparison and benchmark data will provide the tools needed to drive productivity improvement across the sector.

The metrics can be used by organisations to analyse and benchmark performance at a number of levels:

- Industry-wide
- Inter-company across multiple projects
- Project specific across construction site works packages and activities.

Four of the metrics involve measurement and data gathering at site level, the fifth, pre-manufactured value (PMV), is derived from an analysis of the cost breakdown for on and offsite work activities.

This document focusses on the first two measures, productivity and waste generated, where the data was readily available from Taskforce members for completed and under construction projects from across the UK which could be analysed to establish benchmarks.

British Land and Landsec, client members of the Taskforce, also provided open access to the data from a live site under construction to be used as pilot projects. The aim being to work collaboratively to share learnings and, develop the techniques and standardised measurement methodologies needed to gather data using a consistent approach with the least impact on the site teams.

The practical lessons learned from the two pilot projects have been invaluable in informing this framework and underpin the seven-step measurement approach presented.

Further work is planned by the Taskforce to continue to develop and pilot the use and measurement of the other three metrics on live construction projects. The results of these studies will be included in a future update of this framework.

Observations and recommendations from the initial use of the Productivity and Waste Generated metrics on the pilot projects

Table 2 provides a summary of the feedback and learnings from the pilot projects on the onsite data collection process and analysis of high-level Productivity and Waste Generated measures.

TABLE 2
Lessons learned from the use of the Productivity and Waste Generated metrics on the pilot projects

Metric	Observations and recommendations from the pilot projects
Productivity (£/hr)	To ensure consistent measurement and comparison the key definitions to be applied are: • **Granularity:** can be used at an overall project or trade package level • **Value of works to include:** the agreed contract sum or the sum of certified payments to determine earned value of the work • **Number of hours worked to include:** all hours worked on site to deliver the project, including on site labour and site management hours • **Frequency of measurement:** monthly (or more frequently if the above data sets are available) • **Total hours:** any inconsistency in the hours captured will result in erroneous productivity figures and skew the overall average and trends. • Contextual information should be identified to enable data set for each project to be categorised when using this metric, enabling like-for-like comparisons reflecting the project type, size, specification, value, and location. • Calculations must be consistent otherwise it is difficult to establish like-for-like comparisons between projects, and benchmark what is a good practice. • It is useful for obtaining a broad understanding of overall project productivity, using a relatively quick and simple method. Hence, it is good for benchmarking between different projects and to track the productivity levels of individual projects on a month-by-month basis. • This metric can be highly variable if calculated on a month-to-month basis on an individual project depending on the stage the project is at and the activities taking place. More useful comparisons can be made for specific work packages either to track the level of productivity being achieved for a particular activity on a specific project over time or between elements of work between different project sites e.g., demolition/substructure/ superstructure/ envelope/fit-out.

Continues...

Metric	Observations and recommendations from the pilot projects

Productivity
(£/hr)

- When using this metric on a specific work package, be clear on what labour data is included/not included. Depending on the scale and complexity of the project labour resource may be deployed on different activities during a day or on different buildings on the same construction site. Some labour data is "fluid" in that it works across multiple site locations over the course of a day as compared to "static" labour data that works in a single location from day to day. The more accurately the labour can be allocated to the activity the better the productivity assessment. It is important to consider this before work commences on site so that appropriate measures can be put in place to capture the data needed.

- One of the key advantages of this metric is that it is relatively easy to access the data needed to calculate it at the overall project level or by work package. All projects currently track the cost of the works at least monthly to coincide with the valuation cycle and the time individual workers spend on site is recorded (usually electronically) for safety and security requirements at the point of entry/exit. However, its reliance on the cost of the works to assess productivity can skew the results where the material cost of the works varies significantly due to the level of specification, quality of materials used, scope of works, building type and location etc., particularly when comparing one project against another.

A good example to illustrate this is the analogy of installing a gold-plated tap which would result in a higher productivity level than a chrome tap, even though the installation time would be similar. Also, as the data bank is built overtime costs will be subject to inflation so it will be important to baseline the results obtained when comparisons are being made and benchmarks established.

Creating a rule set to ensure consistent data collection on site and capturing contextual information to inform the benchmarking process will be a key function for the Construction Data Trust as it builds its "big data" set across the industry.

Metric	Observations and recommendations from the pilot projects

Waste generated (m3 or Tonnes/ £100k)

- A volumetric measure of waste in m3 is used in the CLC's definition of this metric. However, in practice the waste removed from site is more commonly measured in tonnes using weighing devices on the collection vehicles or at the waste transfer stations and in cases where volume is recorded this is usually an estimate based on the number and size of skips containing waste. Standard conversion factors can be used to translate the figures between volume and weight, but our recommendation is that this metric should use the more accurate measure of weight in tonnes.

  The Environment Agency publish a list of standard conversion factors for different categories of commercial and industrial waste.

- Obtaining waste data broken down by type is an increasingly important consideration, as it allows landfill to be distinguished from recycled/reused material.

- Categorising waste data by type enables insights into the proportion of each type of waste generated on site. This establishes what type of material or activity generates the most waste.

- Plan to use vehicles with weighing capability or obtain the weight of the waste from waste transfer centres with weigh bridge facilities (and a data logging facility), enabling accurate data collection and management.

- Record the distance travelled from site to the waste transfer stations to support carbon impact assessments enabling the project team to identify more efficient disposal processes and reduce vehicle miles and the associated carbon emissions.

- The design solution/construction method has a significant impact on the amount of waste generated on site and can have a negative impact on productivity and carbon footprint as the collection, transporting, and disposing of waste are all non-productive processes.

- Measure waste generated across the supply chain both on and offsite, where possible, to get the full picture for each project. Measuring offsite waste is not commonly undertaken and still requires further work by the industry to develop recommendations in how best to measure and collect the data.

- Collecting more industry-wide waste data, will benefit designers by helping them to understand how certain design solutions / construction methods influence the amount of waste generated on site, and enabling more informed decisions earlier in the process.

Observations and recommendations for the use of these metrics by the Construction Data Trust (CDT)

The importance of measuring and analysing construction productivity is being increasingly recognised and some progress has been made by individual companies. However, a fundamental shift is required before the sector can transition to a data-driven approach.

Although the Productivity and Waste Generated benchmarking metrics being trialled on the pilot projects provide good high-level insights, further work is needed to fully support drill down or further interrogation to determine the key drivers and blockers for improved productivity. However, they do provide helpful benchmarks and can be used to support site-specific metrics and the wider application of the guidance provided in this framework.

While there's substantial data being produced from the pilot projects that can be used to create insights, typically the amount of value that can feasibly be extracted from using the five high level benchmark metrics at a construction site level is constrained by several issues:

- Further work is required to gain more knowledge on the key problem statements disrupting construction site productivity
- A significant quantity of data is manually input into unstructured spreadsheets
- There's inconsistent naming and categorisation in and across data sets
- Significant lag exists between data creation and usefulness
- There are gaps and duplication in data
- Further work is required to agree a set of site-specific metrics to assist in future benchmarking exercises

A lot of the data is created as a by-product of project delivery. There's an opportunity to view this data as a strategic asset that codifies our collective hard-won experience.

The power and potential of site-specific metrics

Although the five high level metrics identified by the Taskforce provide an initial approach to compare overall project performance at industry level and to develop a set of sectoral benchmarks based on aggregated data it was quickly realised that a wider range of multilevel performance site-specific metrics were needed to drive performance improvements.

A granular set of site-specific activity-based metrics were developed within the pilot project studies, some examples of which are featured in the case studies included in this framework. They have the power and potential to measure task-based site productivity and identify productivity enhancing insights.

These metrics were also found to be better at solving specific site productivity disruptors identified by the pilot projects, such as inefficient use of plant and equipment and site logistics issues.

Site-specific metrics are best identified, developed, and applied using the seven-step framework described in the following section to establish the following:

- The metrics to be used
- Frequency of measurement (daily, weekly, monthly)
- Granularity (work package or activity level)
- Establishing benchmarks from previous projects/available industry best practices (using Construction Data Trust data, where available)
- Identifying insights from the collected data in how productivity can be improved

Examples of site-specific metrics measures used on the pilot projects are listed below and more details can be found in the case studies within this document.

Planned v. actual outputs:

- Relating to units of work completed: volumes, areas, tonnage, components etc.

Works package productivity:

- For example, value of works completed per hour of work (£/hrs), or value of works completed per unit of production output (£/cladding units placed) etc.

Labour productivity:

- Unit of production output/total hours worked (e.g., m3 of concrete placed/total hours worked).

Production cycle times:

- Time from start to finish relating to specific work cycles (e.g., concrete floors, units of cladding, piece counts).

Design deliverables to meet programme:

- Relating to % of design information issued and approved on time (e.g., construction issue drawings and BIM models, material schedules, technical submissions)

Logistics metrics:

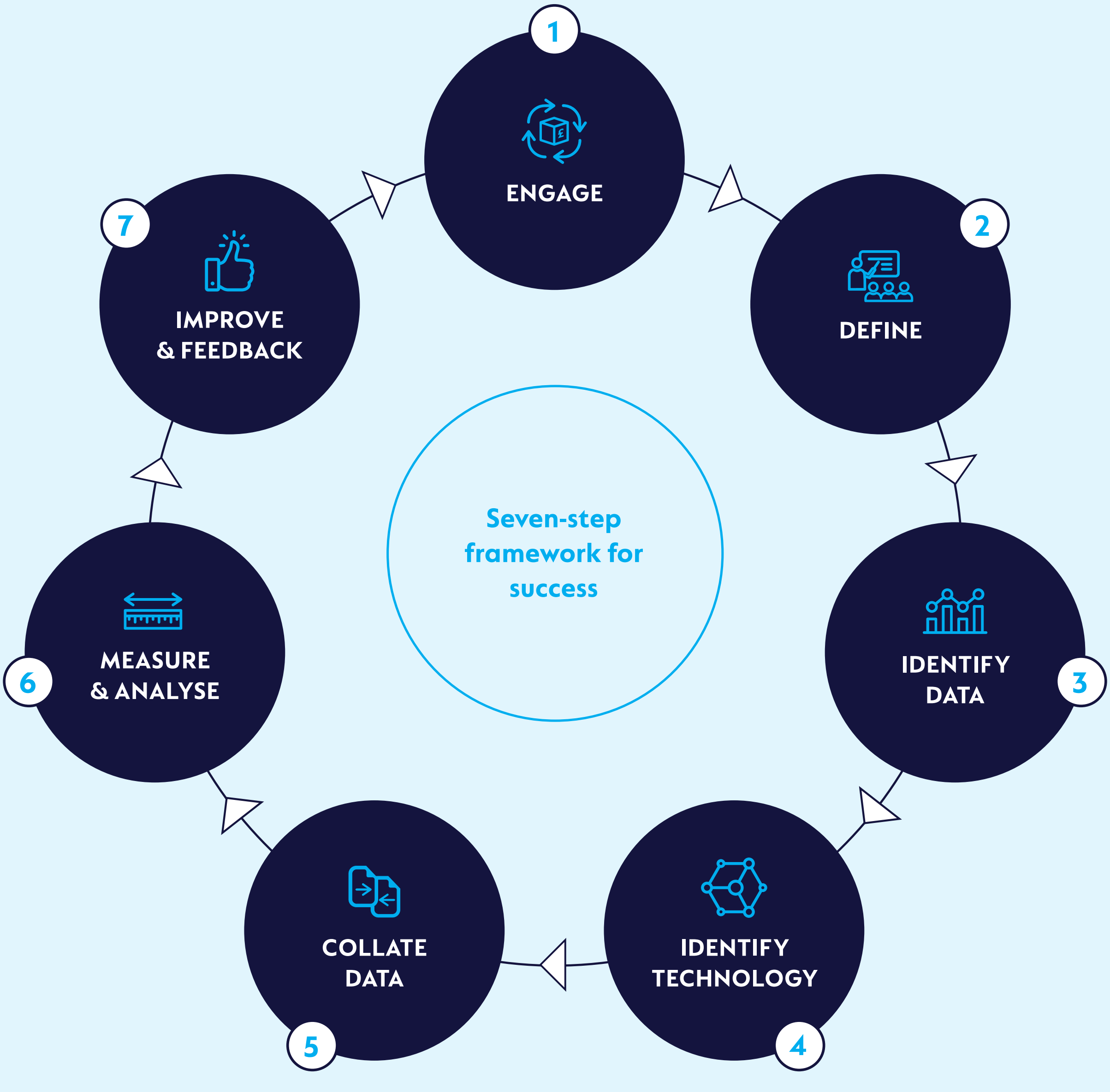
- Planned v. actual deliveries to site, number of vehicles turned away because of site congestion or failure to book a delivery slot, vehicle waiting and unloading times etc.

Plant or equipment utilisation:

- Percentage of time in productive use and time lost due to waiting time, weather impact, breakdowns, maintenance etc.

Our seven-step framework for success

The recommended approach for an effective construction site productivity improvement study should follow the seven-step framework detailed below. Feedback in the form of observations and recommendations from using the framework on the pilot projects is summarised and tabulated in the next section. More detailed information illustrating how it was applied on the pilot projects is included in the case studies within this document.



Observations and recommendations on each step

STEP 1
ENGAGE

Engagement of supply chain partners and key stakeholders

- Identify a productivity lead from the project team (preferably from the main contractor or construction management team) who will facilitate and coordinate the overall study and appoint individuals to lead individual problem statements/solutions.

- Identify key supply chain partners/stakeholders to be involved early in the productivity study, and where possible involve them in the identification of problem statements, data requirements and the productivity data capture plan.

- Secure early senior management commitment and buy-in from all parties (both site and office personnel). This will ensure that things get done and everyone is committed to the collective effort needed for a successful outcome.

- On the pilot projects, the leadership shown by the client and the commitment from the contractors, designers, and suppliers ensured buy-in from the whole team from an early stage as detailed in the case studies within this framework.

- Engage key project team members who can influence productivity.

- In the early stages, the team needs to develop a "have a go" mentality and believe that the study can make a difference.

- As a minimum we would recommend that senior productivity leads or champions should be identified across the client and project team with specific responsibilities to measure, collect and analyse on site construction data. This should include representatives from:

  – Client
  – Design consultant team
  – Project management
  – Construction lead (Build)
  – Construction lead (MEP)
  – Logistics team
  – Design management team
  – Planning team
  – Commercial team
  – BIM//Information Management team
  – Package managers (as required)
  – Key subcontractor/trade contractor leads (as required)

Continues...

- Share examples of the benefits realised from other publicly available productivity studies used in the construction sector and from other industries and from the businesses' own experience to gain greater engagement.
- Productivity insights can lead to actions that significantly improve productivity (in terms of cost and time savings) and can benefit all parties involved. Project teams should consider early in the process how these benefits can be shared from a commercial perspective, to drive a greater focus on productivity improvement.
- Maintain ongoing communications across the project as new team members join – individuals and supply chain
- Establish an open and collaborative approach – focused on building trust in the benefits of collecting the data and measuring productivity and sharing/discussing the output data to identify step-change improvements.
- Share data and have frequent reviews on what it's showing – is it solving the problem statement? Is it highlighting disruptors? Is it helping to identify productivity improvement insights? Does the approach need to change?
- The whole team needs to have a desire to share and learn from each other to get the most out of the study.
- Be clear on why the data is being collected and what it will be used for – so that it's better understood.
- Include the requirements for productivity measurement and data collection in the subcontractor package scope and definition.
- Consider holding awareness/training sessions with all the project team members (including supply chain) to ensure that everyone understands why productivity is being measured, how the data will be used, and the purpose and outcomes being targeted. It is important that everyone understands that the intent is to achieve higher levels of productivity with mutually beneficial outcomes.
- Explore incentivisation opportunities where all parties could benefit from the savings in labour costs and preliminaries resulting from increased productivity. Review contractual terms to identify how incentives can be incorporated (refer to Private Sector Playbook where these ideas are explored in more detail).
- Schedule regular reviews to identify how the whole process can be improved.

Continues...

Identify the opportunities for productivity improvement

- Once the team is engaged, undertake discovery workshops to discuss and identify productivity opportunities.

  First identify key productivity disruptors and possible solutions to these challenges.

  This will enable a data capture plan to be established detailing metrics, data sets, frequency of capture, use of technology, method of analysis and reporting.

- Use the workshops to define problem statements, which can be used to describe activities that are disrupting (or potentially disrupting) or influencing productivity across the project. Identify the supply chain partners most associated with the problem statements.

- Identify where you can make the most difference and can use the data to make positive changes.

  Avoid collecting data that will not be used in the productivity study.

- Be clear on what problem statement you are trying to solve. Everyone involved needs to understand problem solving should benefit everyone, not just the client or main contractor.

- Ensure that the data is identifying insights and is improving productivity and/or eliminating disruptors.

  Be prepared to review and change data collection methodologies and metrics if the insights needed to overcome problems and drive improved productivity are not being identified.

- Assess each problem statement for the key issues impacting on the problem and identify any constraints.

  Prioritise the problem statements in terms of their impact on overall project productivity and related performance objectives: time, cost, quality, safety, carbon, and waste.

  Identify the types of data needed to understand and resolve the problem statements.

STEP 2
DEFINE

Conduct a definition workshop to agree key metrics

- Involve the whole team in the definition workshop to ensure everyone's buy-in to the proposed solutions.
- Identify potential solutions or interventions to resolve the problem statements.
- Review the prioritised problem statements from Step 1 to identify which work packages will most likely resolve the problem, and from this identify what metrics to assess and what data you need.
- Prioritise key problem statements and solutions from Steps 1 and 2 and identify work packages that have most impact on resolving these problems.
- Use the workshop to define and agree the data sets to be captured, method of measurement and frequency of collection.

It is important to identify:

– A list of metrics to be used in the study

– Method of data capture – manual recording, automated processes using QR codes, IoT devices, biometrics, data logging, visual capture AI techniques etc

– Frequency of measurement for each data set (daily, weekly, monthly)

– Level of granularity (project, work package, task)

- Agree which benchmark metrics will be used to drive a solution to the problem statement.
- Agree the site-specific metrics that are needed to solve the problem and drive decisions.
- Remain open to expand the scope of metrics if further benefit is identified.
- Start any productivity study small – to test and learn that the data capture is addressing the problem statement. Further metrics can be added later as improvement insights are discovered.
- Collate benchmarks for the chosen metrics from previous projects/available industry best practices - using the CDT data, where available.

STEP 3
IDENTIFY DATA

Identify key data points needed to measure the key metrics

- Regularly review the data being collected across the project and identify any gaps which could impact on the measurement of the agreed metrics in Step 2.
- Identify potential solutions or interventions to resolve the data gaps.
- Agree the scope of the data measurement, how the data will be sourced and the rules which will need to be applied to ensure accuracy and consistency.
- Agree the method of data collection and analysis and appoint responsible individuals to collect and analyse the data.
- Aim to collect data as frequently as possible – preferably in 'real time' using digital technologies (see Step 5).
- Ensure data capture requirements are incorporated into subcontracts/trade contracts, including the allocation of specific resources with responsibility to capture data.
- Aim to collect site-specific data on appropriate work package cycles – such as floor cycle times, unit installation times, overall activity start and finish times – and not necessarily just on daily, weekly, monthly intervals.
- This allows for variation across individual cycle times to be integrated into an overall 'start' and 'stop' activity cycle.
- Collect additional information which may assist with the data analysis, such as the size or weight of a component or area of a concrete pour, floor level of the activity, complexity of the work processes, etc.
- Also, any features that could impact on the productivity of a particular activity, for example access, obstructions, openings, beams, upstands, etc. It may help draw more informed learning from the data.

STEP 4

IDENTIFY TECHNOLOGY

Identify and integrate suitable technologies to capture the required data

- Assess the use of digital technology to streamline data capture and assist in collecting it in 'real-time'.
- Can the data capture/analysis processes be automated?
- Automate the data and capture the influencers that have the most impact on productivity, e.g., labour, site constraints, logistics, weather, etc. More frequent data collection enables faster decision/action intervention.
- As well as potential efficiency gains from using technology to capture data, automation of data collection significantly improves data quality and consistency.
- However, the use of technology will usually result in a greater volume of data being generated that needs to be efficiently managed and analysed.
- Choose technologies carefully to ensure the data collected meets the study's requirements. Ensure a plan is in place for how data will be analysed to generate insights to assess and improve productivity.
- The technologies used should be linked to a clear process for generating insights and informing decision making.
- Use technology to enable where needed more frequent data capture which would be difficult to achieve using manual methods, e.g., by the hour or minute.
- For some activities being able to analyse the data in a greater level of detail may assist in identifying blockers that are disrupting the process and preventing the optimum productivity level from being achieved.
- Use technology to standardise the acquisition of data sets across multiple projects being delivered by your company which will enable you to obtain a broader perspective on patterns and trends and to identify outliers where productivity levels have diverged from the norm.
- Most construction sites now use automated systems to record the number of people on site using access control systems using identification cards or biometric sensors which provide a digital record of the times of entry and exit.
- These records are linked to database data which identifies the individual, the organisation they work for and usually their job title or role. The information can be used to link the labour resource to a particular work package/organisation and categorise the people on site by their role – site operative, supervisor, and manager etc.
- This enables a base level of analysis and interrogation of the labour resources being used to carry out a particular activity when linked to the measurement of output achieved during any period but may not have the level of definition needed on more complex sites where there are multiple workfaces and sometimes more than one building where the resource is being used.

Continues...

Where a greater level of detail is required to facilitate more rigorous analysis of how labour or other resources are being allocated to different tasks and work areas across the site it is important to consider what additional technologies could be deployed to capture the data needed, ideally in real time.

This will be particularly important for the tool time metric which has been recognised as probably the most challenging of all the five high level metrics identified by the Taskforce to measure on site on a consistent basis.

- Examples of technologies that can be used to capture productivity, quality control and progress related data in 'real time' include:
  - IoT sensors attached to people, plant, equipment, components, and materials and combined with some form of geolocation tracking – in the case of individuals any personal tracking technologies will need their permission to be used and comply with GDPR requirements
  - Visual technologies that enable comparisons between BIM models and actual site progress
  - Material and component tracking – QR codes, bar codes, RFID tags NFC tags, Bluetooth low energy, etc.
  - Task completion recording and visual data capture using mobile site management tools (mobile phones, tablets etc)
  - Plant and equipment performance monitoring, e.g., crane and plant telematics, hoist telematics
  - Visual data imaging and scanning collection techniques to record progress (video/360-time stamped photography, 360-degree camera audits with AI augmentation, point cloud surveys)
  - Embedded temperature sensors in concrete floor structures used to monitor the curing process and predict strength gain
  - Embedded sensors in concrete piles and foundations which can be used to provide condition data over their life – allowing improved condition assessments in the future to allow foundations to be re-used

STEP 5
COLLATE DATA

Collate the data capture plan: mobilise technologies and processes to streamline data collection

- Establish a productivity data capture plan from the outset to summarise the outputs from Steps 2, 3 and 4 – including what to measure and how to collect data. Ensure the plan is realistic and achievable.
- Agree a timescale to trial data capture, analysis, and review for each problem statement.
- Establish data management and governance processes – including revision control, data security and non-disclosure protocols across the project team.
- Regularly review and update data capture plan as part of a continuous improvement process.
- Only measure/capture key data to address the problem statement – don't try to measure everything.
- Adopt a consistent (and where available, industry standard) naming convention to identify organisations, work packages, labour, plant, equipment, and material resources etc, to establish a common data classification which can be used by all the digital tools being deployed.

STEP 6
MEASURE & ANALYSE

Measure, analyse and review to test the metrics and identify productivity improvement insights

- Undertake initial measurement trials to test the metrics: evaluate if the outputs are enabling improvement insights to be identified.
- Schedule regular review sessions with the project team to:
  - Review the data and identify productivity improving insights
  - When required implement improvements to the metrics
  - Check that the process is improving productivity
- Compare planned v. actual labour levels against planned v. actual output, to establish a clearer picture of productivity.
- Review the metrics being used to determine if they are providing the expected insights into the problem statement.
- Use the data captured to drive productivity improvements that can be implemented throughout the construction phase from level to level and/or between buildings. Record and share those interventions that had a material improvement on productivity across the whole project team and build them into working practices, to drive continuous improvement in productivity.
- Capture learnings for metrics that 'did not work' or did not identify the expected productivity insights – this will be valuable for future studies.

STEP 7
IMPROVE & FEEDBACK

Implement productivity improvements and feedback on results

- Share your data in anonymised form with the CDT to help establish a robust databank of productivity benchmarks and best practice for use across the industry.
- Hold lessons learned workshops with the project team and key stakeholders to develop better measurement and analysis methodologies and identify process improvements that can be implemented to improve onsite productivity. It is recommended that the frequency of these workshops is agreed at the outset of the study to suit the work package and activity being undertaken (e.g., daily, weekly, or monthly).
- Identify design issues that both positively and negatively impact on productivity and feedback through the lessons learned programme to ensure negatively impacting issues are not repeated on future projects.
- Collate and record the results from the project productivity study to provide feedback to your own organisation for use on future projects at the start of the engagement process (Step 1).

Overview of the pilot projects

The Forge, Southwark, London

Landsec's landmark commercial office development, The Forge, is a 140,000sqft scheme located to the West of Southwark Bridge Road close to the Tate Modern at Bankside.

Comprising two new eight storey-office buildings and a public courtyard, The Forge is the UK's first Net Zero Carbon (NZC) commercial development recognised by the UK Green Building Council as aligning with its framework definition of NZC in construction and operations, and the first office to be built using the highly sustainable platform approach to design for manufacture and assembly (P-DfMA).

The project has been awarded funding from Innovate UK, part of UK Research and Innovation, for its pioneering design and ground-breaking construction techniques, which has contributed to a circa 25% reduction, to date, in embodied carbon from the initial design stage.

The objective of the build is to use innovation and modern methods of construction to target improvements across some or all the following five measures: 'Faster, Better, Cheaper, Safer, Greener'.

To achieve this, Landsec has assembled a team based on their innovation credentials including the designers, Bryden Wood, and joint venture contractors Mace and Sir Robert McAlpine providing construction management services.

Building offices using 'kit of parts' platform design, automated construction processes and digital technology will revolutionise office construction, making it safer and more productive, reducing time, cost and carbon emissions, helping the UK to meet its target to be NZC by 2050.

The scheme completes at the end of 2022.

Norton Folgate, London – British Land's Blossom Street development

Norton Folgate, British Land's Blossom Street development, refurbishes and extends historic warehouses and creates new buildings to deliver 340,000sqft of modern workspace and associated retail close to Liverpool Street Station.

The project is creating sensitively designed buildings, using a combination of offsite manufacture and traditional methods, to bring many vacant or underused buildings in the area back into useful economic use.

To deliver this project, British Land put together a design and build team led by Skanska as main contractor, AHMM as architect, with support from Stanton Williams, Morris + Company (MoCo) and DSDHA. Arup and AKT II are MEP and structural engineer respectively.

Early whole team engagement has enabled strong collaborative relationships to be established to better understand this project's complex and bespoke requirements. This has included the development of an offsite prefabricated façade solution, that has helped reduce the original build programme by three months.

The scheme completes at the end 2023.

Case studies from the pilot projects

The following case studies summarise how the seven-step site productivity measurement process, described above, was applied to the pilot projects, together with the learning and insight gained about productivity measurement and improvement.

Productivity measurement as defined in this framework is continuing in the pilot projects and further case studies are planned as a future update to the framework.

Case Study #1

The Forge
Mechanical & Electrical Services Installation

Case Study #2

Norton Folgate
Reinforced Concrete Frame Construction

Case Study #3

The Forge
Waste Minimisation & Measurement

Case Study #4

Norton Folgate
Tower Crane Utilisation

Case Study #1

The Forge
Mechanical & Electrical Services Installation

Location
Central London, UK

Client
Landsec

Designer
Bryden Wood

Manufacturing & Assembly Manager (MAM)
Mace/Sir Robert McAlpine
(joint venture partnership)

Supplier
NG Bailey Manufacturing

Works Description
Data collection for MEP
on-floor services installation

Background

The Forge project has adopted a Platform Design for Manufacture and Assembly (P-DfMA) approach to delivery. The innovation focusses on the three fundamental elements of a building: structure, envelope, and M&E services. In a commercial office, these often account for over 60% of the project spend. This case study focusses on the on-floor Mechanical & Electrical (M&E) services installations which form a key component of the 'kit of parts' used.

Elements of M&E services installations are increasingly being prefabricated offsite. The use of riser modules, pump skids and preassembled plantrooms is becoming commonplace on larger projects with constrained sites and tight timescales.

However, in most cases the decision to take this approach is made late in the project, when it's difficult to make changes and less cost-effective, resulting in much of the potential opportunity being lost, particularly on the office floors.

So, what's so different about The Forge?

The answer is the early input into the design of the preassembled M&E components by the manufacturer. This enabled the design team to fully integrate the M&E services with the P-DfMA structure, not just for risers and plant spaces but also for the on-floor installations.

By working together, Bryden Wood and NG Bailey rationalised the 'cassette module' (see below) variants needed across the project and then optimised them for ease of manufacture and assembly.

The resulting components have a high-level of standardisation and are optimised to work with the structural system enabling the identical design to be used on other buildings constructed using the same systemised approach. This follows the manufacturing adage of 'design once, use many times.'

In common with many modern office developments the client wanted to expose the structure and high-level services in the office to maximise the volume of space and create a more industrial aesthetic. The highly integrated design minimised the structural and services zone to maintain a clear height of 2.75m within an overall slab-to-slab height of 3.7m. The repeatable nature of the installation ensured a high-quality finish.

As part of the P-DfMA design for The Forge, the installation of the on-floor services was rationalised into three main types of 'cassette modules' that could be factory preassembled, delivered to site and then lifted into place and secured. The cassettes were supplemented by a Unistrut support frame, ductwork extension pieces and a ceiling lighting raft which were all provided by the factory in kit form for ease of installation.

The P-DfMA structure comprised a primary steel frame spanned by a flat slab concrete floor with in-built secondary concrete beams. The reusable temporary works used to form the slab included cast-in fixings set out on a regular pattern to facilitate the installation of the services cassettes' which are suspended from the soffit. Approximately 23,500 were provided removing the need to manually post-drill the concrete slab, speeding up the installation.

Each cassette module and set of components was subjected to a thorough QA check at the factory to minimise any problems on site. The cassette modules were given a QR code to enable them to be tracked through the manufacturing and installation process and the time taken to install each of the six main components which make up the M&E services kit of parts is recorded daily to allow a full analysis of productivity levels achieved on the project.

FIGURE 1 – Modules are made under factory conditions

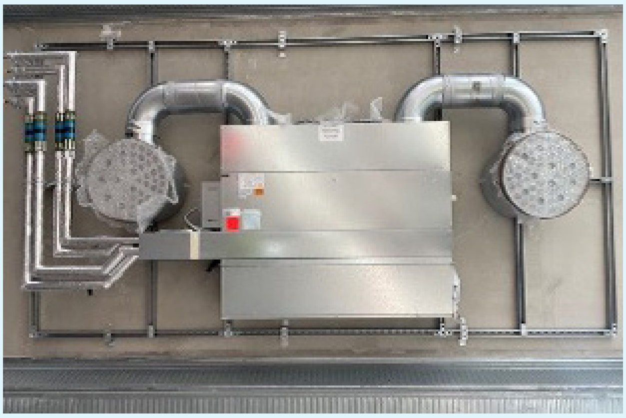


FIGURE 2 – Fan coil cassette secured to the soffit

FIGURE 3 – Installing various cassettes to complete the bulk of the M&E on-floor services

The processes applied on the project follows the seven-step framework.

STEP 1
ENGAGE

Landsec appointed NG Bailey Manufacturing, under a pre-contract services agreement (PCSA), to work alongside the designers. Their role was to help develop the on-floor services design and consider the manufacturability, ease of installation, efficacy, and cost. Early in the process, representatives from the NG Bailey factory team worked alongside the M&E designers in Bryden Wood's offices to produce a fully detailed design.

This project phase allowed productivity improvements to be made, and solutions to the challenges found by the joint team. The early appointment of the manufacturer was done under a PCSA, following a competitive bidding process that considered unit pricing, design capability, manufacturing capacity and quality. To retain some commercial tension the PCSA was for the design stage only and the contract to manufacture and install the cassettes was tendered at a later stage.

The project was procured under a construction management form of contract which enabled the client to engage directly with supply chain specialists like NG Bailey to drive forward the scheme's innovation objectives. Construction management services were provided by joint venture contractors Mace and Sir Robert McAlpine acting as Manufacturing and Assembly management specialists for the P-DfMA elements of the project, hence the acronym 'MAM'.

STEP 2
DEFINE

Because this was an innovative platform design and delivery method, there was a desire by all project stakeholders to gather and interpret M&E installation phase performance data. This was to be captured to the nearest minute for every individual cassette. In addition, any re-works or blockers were also recorded.

The key driver for the project team was to understand how quickly the M&E cassettes could be fitted into position to optimise the floor cycle time and to gain insights into how to improve the process. The installation methodology was based on an automated construction process carried out by four teams of four operatives.

Before starting on site, a prototype building slice was constructed at the Construction Platforms Research Centre in Hampshire, which enabled the installation teams, using the cassette modules and kits, to test the times taken to install the high-level services. This provided a benchmark target for the site team to work towards.

STEP 3
IDENTIFY DATA

These key data points were initially identified for collection:

- Lorry delivery miles
- Benchmark installation timings (from the prototype)
- Onsite installation timings
- M&E floor fit-out team size
- Testing feedback, quality/leaks, etc.
- Rework actions
- Onsite waste levels

STEP 4
IDENTIFY TECHNOLOGY

The basic data collection method used QR codes fixed in the factory to each cassette assembly. By scanning these during manufacturing and transport, progress offsite could also be monitored.

Once delivered to site, the codes were scanned again, as the installation started and finished for each item.

NG Bailey has developed its own software platform to enable QR codes to be easy to use by their site operatives. Installation times recorded on site were benchmarked against the prototype trial results and from floor-to-floor and team-to-team. Qflow and Tracker+ software was used to record the materials delivered, and the waste taken from site, for each trade contractor.

The Qflow software uses AI to analyse data from delivery and waste transfer notes captured at the site gates and provides an estimate of the level of embodied carbon in the materials used.

The installation is subject to rigorous inspection and any rework required is collated on the Aconex Common Data Environment (CDE) system, which manages the project data.

Blockers and disruptors impacting on the works progression and onsite productivity such as site access issues, obstructions in the work area, failed fixings and bad weather etc., were recorded manually during the install process.

Everyone is required to swipe in and out of the site and the time and attendance records are stored on the Datascope access control system. This information is combined with details from NG Bailey to determine each installation teams' size and makeup.

STEP 5
COLLATE DATA

The data capture plan was then developed, combining the data points identified in Step 3 with the appropriate measurement method identified in Step 4.

The data collected was then used to develop measures which respond to the five key productivity related metrics identified by the Construction Productivity Taskforce:

Productivity
Time and labour resource v. floorplan area installed

Waste generated
Collection of on and offsite wastage levels

Pre-manufactured value
Value of work done in assembly factory v. total contract value

Right first time
Feedback from QA inspections, testing and commissioning and levels of rework

Tool time
Time taken to install the modules

All the key stakeholders agreed to a plan which was then overseen by the Manufacturing and Assembly Manager (MAM).

STEP 6
MEASURE & ANALYSE

Data collected from the first nine weeks of installation on site is very encouraging. The initial findings have been benchmarked against the component installation timings achieved on the trial installations, carried out by NG Bailey on the prototype.

The data collected on site, using the QR codes to track the installation progress, and the visual observations recorded by NG Bailey and the MAM, have been shared with a Cambridge University Construction Engineering and Technology research team, who are analysing the information to develop productivity metrics for the on-floor M&E kit of parts installation.

The raw data is showing most of the installation processes are faster than the benchmark times recorded:

Cassette type	Target time from prototype in minutes	Actual time to install on site in week 9	Improvement over benchmark in minutes
UnistrutPiece	9.5	8.4	**1.1**
FCU	34.0	30.7	**3.3**
Comflor	47.5	27.2	**20.4**
Pipework	20.5	42.0	**-21.5**

The chart in **Figure 4** clearly shows the improvement in the installation times over the first nine weeks of the M&E cassette installations. This has been partly due to the natural learning curve of the site teams but the step change improvement at week six for the larger cassette units was driven by a change in installation methodology – using mobile forklifts with specialised lifting rigs in place of the genie lifters used over the first five weeks.

The MAM digital team is currently using a Power BI dashboard to view the data, which will help the construction team to continue to draw actionable insights that can be implemented quickly to improve onsite performance. The data analysis is being developed with input from the Cambridge University team and the CDT to ensure it is robust and independently verified. This will then produce productivity metrics that fully align with the CLC guidelines.

Is the boat going faster?

Yes, it certainly is, as evidenced by the improving installation times.

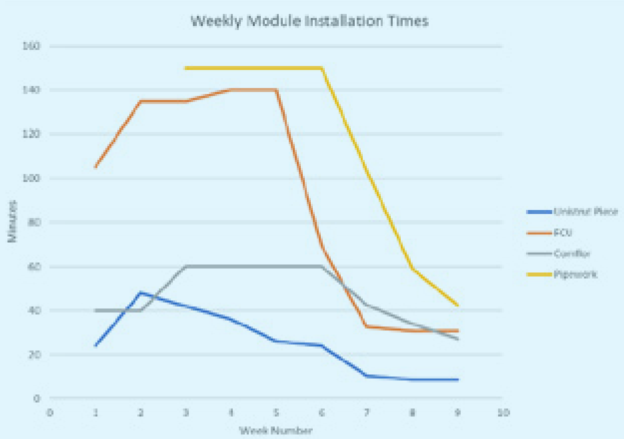


FIGURE 4 – Installation times recorded over the first nine weeks

STEP 7
IMPROVE & FEEDBACK

Ongoing lessons learned capture sessions are being held with the project stakeholders. The P-DfMA methodology allows these learnings to be fed back into the model design, ensuring that the improvements are embedded into the components for future projects.

The goal of designing to promote industrialised construction, by increasing the Pre-Manufactured Value (PMV) of the build's offsite manufacturing element, has been achieved and this will be further improved through the successive use of the systemised approach.

As more standardised, repeatable, M&E cassettes are created, it opens the possibility of increasing automation levels, both in the factory and onsite. **Figure 5** shows the mobile forklift and specialist lifting rig which had such a dramatic impact on the installation times in use.

The use of the digital tools employed on the project is being reviewed to inform how well they performed and determine if any improvements are needed.

The team believe that, wherever possible, data capture should be automated to minimise the need for the site teams to capture data manually and maximise the accuracy of the data collected.

The results from this study have been shared with the project team members and external stakeholders including UKRI Innovate (UK who selected The Forge as a Demonstrator Project for the Transforming Construction Challenge programme), Cambridge University, and the Construction Data Trust.

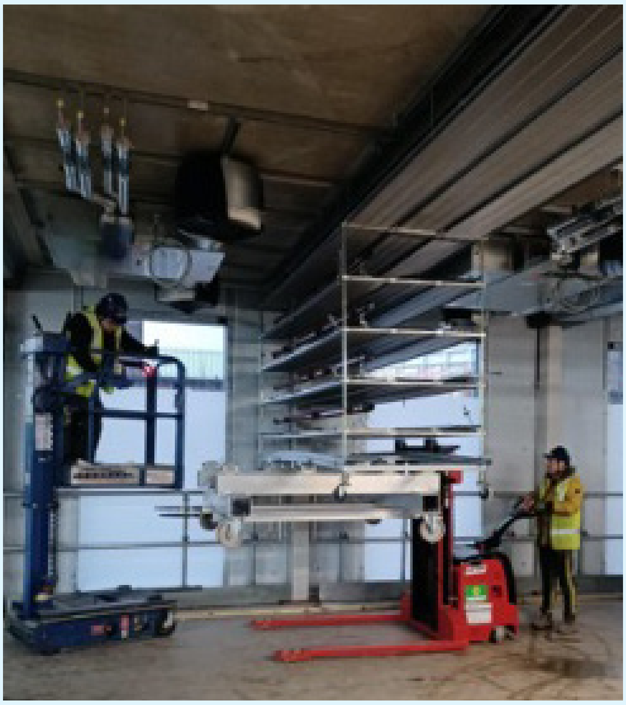


FIGURE 5 – Use of stillages and lifting equipment to improve installation productivity

Case Study #2

Norton Folgate
Reinforced Concrete
Frame Construction

Location
Central London, UK

Client
British Land

Main Contractor
Skanska

Architect
Blossom Yard (plot S1) – AHMM
Elder Yard (plot S2) – Stanton Williams

Supplier
AJ Morrisroe + Sons

Engineer
AKTII

Works Description
Construction of an insitu reinforced concrete frame to a 10-storey new build office building

Background

Norton Folgate is British Land's Blossom Street development, refurbishing and extending historic warehouses and creating new buildings to deliver 340,000sqft of modern workspace and associated retail.

Cantillon Demolition Ltd (now part of the Morrisroe Group) was appointed by British Land at an early stage to undertake a strategic review of the demolition and construction strategy. This process identified the potential programme benefits of combining the demolition, basement and structures packages, and the potential to de-risk the scheme by providing greater assurance through a single point of responsibility.

In situ design and build solutions were required owing to the existing structures and façades which were to be retained and incorporated into the fabric of the new buildings. An exceptional level of experience, skill and construction finesse was therefore required through the construction phase.

The project involves four architectural practices working together across the different buildings: AHMM, Stanton Williams, MoCo and DSDHA. The decision to construct the primary structures as concrete frames was driven largely by the architectural vision for "fair face" or exposed concrete finishes on four of the buildings.

Cantillon undertook the main demolition works, including strengthening, façade retention, piling and bulk excavations, having secured the full basement box package appointing A J Morrisroe + Sons to construct a single storey piled basement.

AJ Morrisroe + Sons separately secured the superstructure package to construct five separate primary concrete frames varying in height between four and 14 floors and being constructed as a mix of insitu-concrete and post tensioned frame construction.

The six buildings are described as Blossom Yard (S1), 15 Norton Folgate (S1a), 9 Blossom Street (S1b), Nicholls and Clarke Loft and Warehouse (S1c), Elder Yard (S2) and Loom Court (S3.), with a total internal floor area of circa 360,000ft2

Productivity data study

This case study focusses on the productivity data that was collected during the construction phase of building Blossom Yard and Elder Yard.

For Blossom Yard, the productivity study focused on the construction of the insitu concrete frame from ground floor to the roof.

For Elder Yard, a more focused study was undertaken relating to the construction of lobby slabs and main slabs, both of which had different design solutions. Lobby slabs were designed as traditional “beam and slab” whilst the main slabs were post tensioned flat slabs.

The processes applied on the project follows the seven-step framework.

STEP 1
ENGAGE

Through a process of early involvement British Land appointed specialist demolition contractor, Cantillon Demolition Ltd, to develop a demolition and construction strategy. Cantillon were able to engage specialist concrete frame contractor A J Morrisroe + Sons at this early stage so that buildability aspects could be considered at the earliest. Complex temporary works design solutions were required for the demolition of the existing and retained structures and for the interface of the old structural elements with the new elements across the whole development.

This early engagement process enabled construction sequencing to be developed and optimised, providing greater visibility for British Land. It also enabled British Land to select the right specialists for the construction phase. This in turn supported British Land's ongoing procurement process of Skanska as the main contractor for the project.

British Land, Skanska and AJ Morrisroe + Sons identified an opportunity to undertake a productivity study initially on Blossom Yard to measure and monitor productivity output of an insitu concrete frame building and to see if the data could provide insights into how productivity can be improved.

Similarly, on Elder Yard, the design solution for the lobby slabs, involving insitu drop beams (see **Figure 1**), had proven to be complicated and challenging to deliver.

FIGURE 1 – Lobby slab/beam with Elder Yard core

Continues...

A productivity study was subsequently identified to look at the labour input required per m² to undertake these works against the labour input required to construct the traditional post tensioned flat slab (PT) methodology employed in the adjacent floor areas of the main slab areas (see **Figure 2**).

Data collection and analysis during the construction phase provided the opportunity for a review of the design intent for the lobby slab, and a comparison of these to be made with the main post tensioned floor slab design.

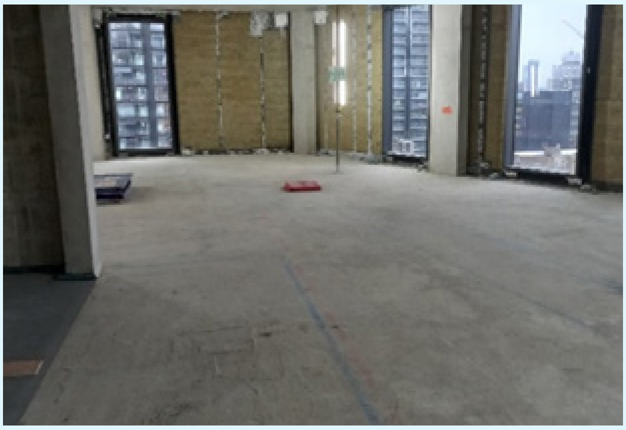


FIGURE 2 – General soffit/slabs designed as post tensioned flat slab

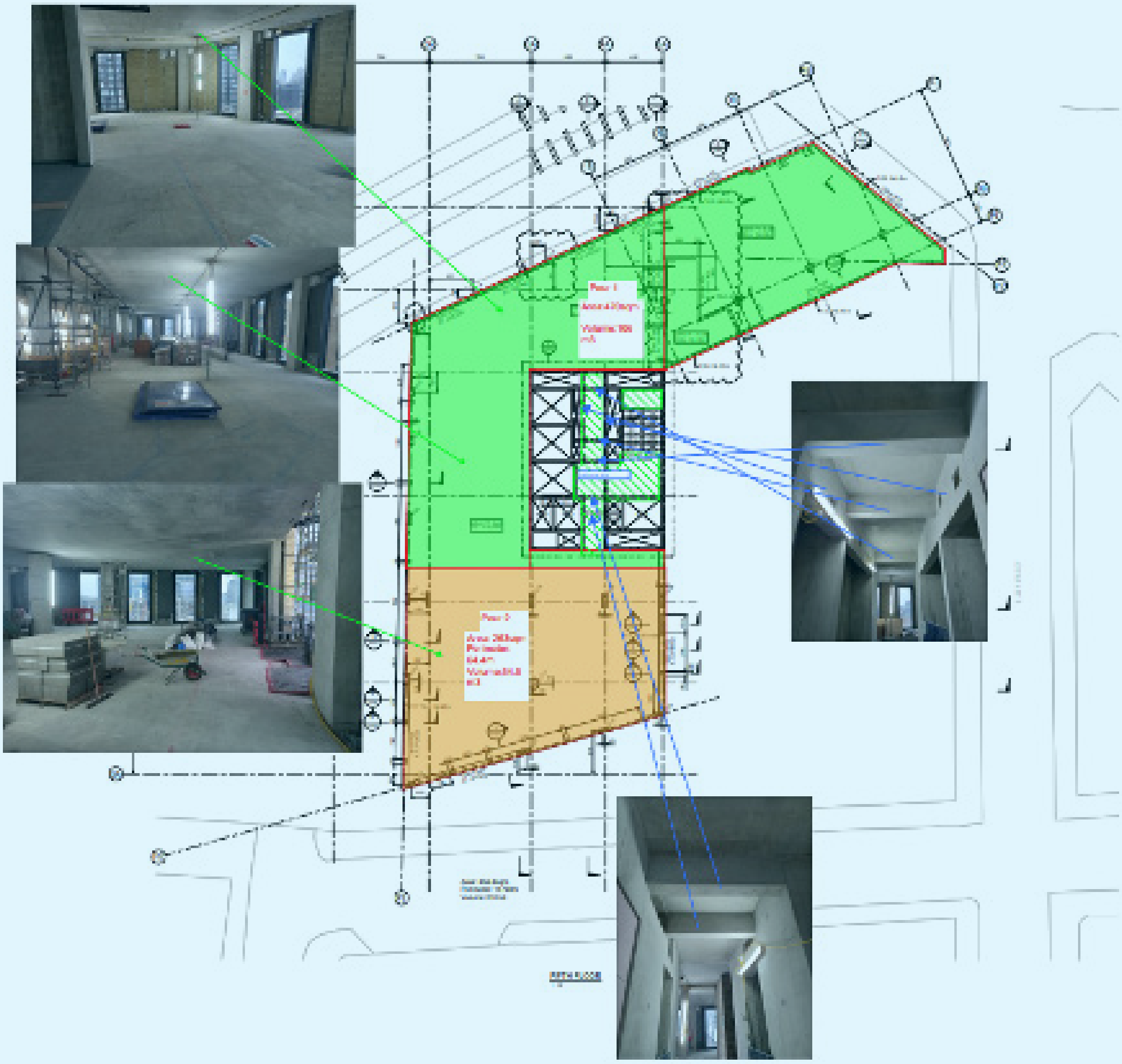


FIGURE 3 – Elder Yard: Plan showing the whole slab areas in both green and orange. Lobby beam/slabs are hatched in green.

STEP 2
DEFINE

British Land briefed all key stakeholders on the objectives of the pilot case study, particularly in relation to 'labour' productivity data capture. A data platform was set up by Skanska and AJ Morrisroe + Sons to capture a wide range of data designed to measure the productivity of all trades involved in the construction of the concrete frame to Blossom and Elder Yard buildings.

On Blossom Yard, the following productivity metrics were collected as part of the study:

- **Work package productivity**
  (£ earned/ hours worked – monthly)
- **Labour productivity**
  (hours worked/ volume of concrete placed m3 – daily)
- **Multifactor productivity**
  (£ earned / volume of concrete placed m3 – monthly)
- **Floor cycle times**
  (days to complete concrete works – per floor level)

Work package productivity and multi-factor productivity were measured monthly, as the measurement timescale was dictated by the monthly reporting of earned value on the project.

Labour productivity was measured daily, with hours worked determined as the sum of carpentry, steel fixing and concrete placing trades in addition to site supervision staff.

On the Elder Yard study, the design required two different construction methodologies to be employed in different work areas on each floor (see **Figure 3**). A better understanding of the practicalities and efficiency associated with each solution was considered valuable.

For this study, the hours worked was collected for each of the two slab designs against the area of floor slab constructed: (i) drop beam slab construction methodology (in the lobby) and (ii) standard flat slab construction with post tensioning (in the main floor plate).

External influences and productivity blockers:

So that meaningful conclusions could be drawn from the data it was necessary to consider and identify external influencers and blockers that were known to disrupt productivity. These included:

- Site logistics & coordination with trades – restricted traffic movements/pick up points
- Restricted laydown areas to service the build and optimise crane usage
- Crane strategy – resulting in unplanned higher demands on crane usage by individual subcontractors
- Formwork and falsework allowances
- Required highly specified architectural finishes
- Weather impact

STEP 3
IDENTIFY DATA

The following data was collected and analysed in relation to the productivity study:

1. Volume of concrete placed per day
2. Labour hours – subdivided by site supervision, carpenters, steel fixers, concrete placement teams
3. Value earned by the works
4. Floor cycle times – to complete all concrete construction operations per floor
5. Crane availability
6. Planned verses actual activities per week
7. Schedule performance Index (SPI) for the concrete works activities
8. Weather disruption

STEP 4
IDENTIFY TECHNOLOGY

Data was collected digitally by AJ Morrisroe + Sons primarily as daily labour and concrete placement returns on to a central spreadsheet, supplemented with daily progress reporting and monthly value earned data, which was then passed to Skanska.

Skanska collected, analysed, and consolidated all the data sets and used Power BI to present and report the collected metrics in real time, as illustrated in **Figure 4**.

The study identified that the manual collection of labour and plant utilisation is very time consuming, particularly labour and plant that is deployed site wide (e.g., tower cranes and concrete finishing teams).

It is therefore strongly recommended that future productivity studies plan to collect this data by digital methods.

As a result of this study, work is ongoing at the Norton Folgate project to develop and test digital technologies to track and collect labour and plant utilisation data in real time. The output of this work will be the subject of a follow up case study to this framework.

STEP 5
COLLATE DATA

A data capture plan was developed, combining the data points identified in Steps 2 and 3 with the appropriate measurement method identified in Step 4.

This then allowed the data collection process to be streamlined from data collected manually on site, consolidated, and analysed in a central spreadsheet, and presented in a Power BI format.

The presented data was then reviewed and analysed by the project team on a daily, weekly, and monthly basis to identify trends and insights into what the data was showing.

STEP 6
MEASURE & ANALYSE

For the Blossom Yard study, **Figure 4** shows a summary of the productivity data collected over the construction period.

The data collected shows that as construction progressed, work package productivity in terms of value earned per hour worked steadily increased as the works progressed, indicating production was steadily increasing. This is backed up by the multi factor productivity, that shows that the value earned per volume of concrete placed was steadily reducing.

However, the works package productivity then dropped off towards the end of construction (with multifactor productivity increasing), indicating that production output was decreasing.

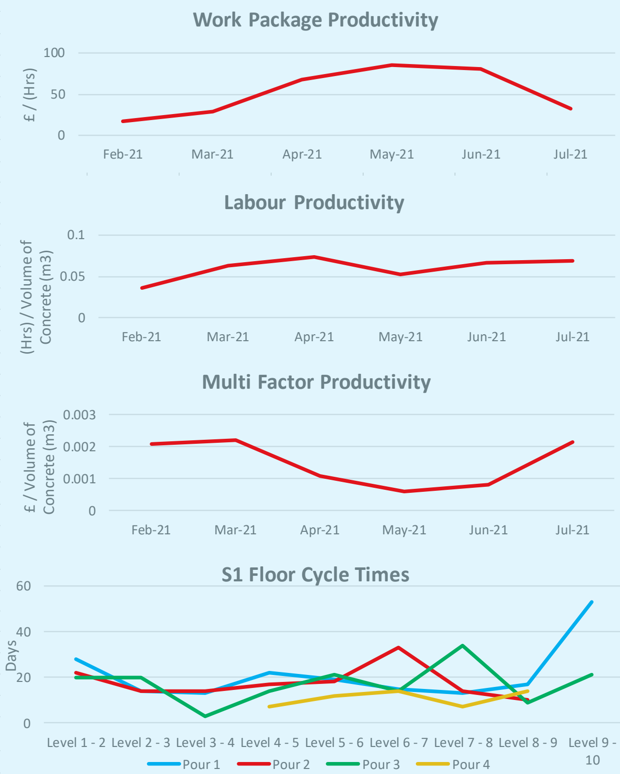


FIGURE 4 – Blossom Yard – insitu concrete frame productivity metrics

Continues...

These effects can be more easily seen in the floor cycle times data, that shows an initial longer cycle time at the lower floors, which then reduced to a constant rate of production output over the middle floors, before increasing again at the higher floors at level 8, 9 and 10. It is clear from this data that something changed or occurred in the construction of the higher floors that disrupted productivity.

Further investigation into this data showed that at floor 9 and 10, the slab design required a higher number of cast-in items, more complex geometry, and the construction of a structural steel transfer structure to reduce floor loading on an adjacent existing core. These additional works resulted in work package productivity slowing at these levels and thereby increasing floor cycle times.

These were interesting findings that showed the metrics, and particularly the floor cycle time are effective at identifying productivity insights.

The main findings from the Blossom Yard study were:

- All the metrics were found to be useful for identifying trends in productivity (e.g., they were all sensitive enough to identify changes in productivity from month to month).
- Metrics that used value earned in their calculation, were less useful because the commercial data was only available monthly and well after some of the work had been completed.
- Metrics that use time or units of work (e.g., volume, areas, numbers), which can be collected daily, were the most effective at identifying insights.
- From the four metrics measured in, floor cycle times was shown to be the most effective at identifying productivity insights, that could be readily acted upon.

For the Elder Yard study, **Table 1** shows a summary of the productivity data collected. The data collected shows that as construction progressed, the post-tensioned flat slab construction was nearly three times faster to construct (per m2 of slab) than in situ drop beam construction.

TABLE 1
Elder Yard – comparison of productivity rates for a post-tensioned flat slab verses insitu drop beam construction

Extracted results	Total tradesmen involved	Labour (hours)	Labour (days)	Floor area (m²)	Productivity rate
Main slab (post-tensioned flat slab)	6	192	4	236 m²	0.81 hours/m²
Lobby Slab ('drop beam' slab)	2	176	11	83.5 m²	2.11 hours/m²

Continues...

Other insights and observations on the productivity data presented:

- The double handling of materials due to restrictions on laydown impacted crane hook time which had a knock-on effect on formwork production/rotation.
- Maintaining access systems within floor areas was challenging. This resulted in some re-sequencing of the works which resulted in some unforeseen delays.
- Lack of laydown for jump core systems resulted in the suspension of the works to de-commission laydown areas and demobilise the systems from within the footprint of the building impacting programme
- Introduction of structural steel cast-in elements (as part of the transfer structures) as support for the reinforced concrete works at higher level impacted cycles and changed the sequence

STEP 7
IMPROVE & FEEDBACK

Overall, the productivity studies undertaken were able to identify productivity insights that can be used on future projects to improve productivity and thereby boost production.

Key learning points

What we learned about the data process:

- Works package metrics that use time or units of work (e.g., volume, areas, numbers), and that can be collected daily, are the most effective at identifying productivity insights.
- The use of digital technologies to collect data in real time should be considered from the outset of any productivity study. Particularly, identifying and developing solutions to collect labour and plant utilisation across the whole project.

What we learned about the construction process:

- Tower cranes selection/allocation should be better aligned with specialist requirements, so that both capacity and output are suitable for the planned works.
- Adequacy of storage laydown areas and access requirements required by the specialists should be fully considered and incorporated into the construction programme.

Case Study #3

The Forge
Waste Minimisation & Measurement

Project
The Forge

Location
Central London, UK

Client
Landsec

Designer
Bryden Wood

Manufacturing & Assembly Manager (MAM)
Mace/Sir Robert McAlpine
(joint venture partnership)

Suppliers
Qflow/Tracker Plus/DataScope

Works Description
Minimising construction waste and improving waste measurement and reporting

Background

The Construction Productivity Task Force has identified that efficient and productive construction projects generate less waste. It has adopted the CLC benchmark measure of Waste Generated related to construction spend as one of five key industry wide benchmark measures needed to help drive the transformation of the construction sector.

In 2018 construction and demolition businesses in the UK generated 67.8 million tonnes of non-hazardous waste (DERFA report – UK Statistics on Waste, July 2021). To put this in context, according to a study by WRAP this level of waste in construction contributes over a third of the UK's total yearly waste[5].

However, on a positive note, 62.6 million tonnes of this were recovered, equating to a recovery rate of 92.3%. To continue to improve the level of recovery and minimise waste sent to landfill the Waste (England and Wales) Regulations 2011 requires all businesses to properly manage and dispose of inert waste and confirm that they are following the waste management hierarchy:

- **Reduce**
- **Reuse**
- **Recycle**
- **Dispose**

Some waste streams contain hazardous substances which fall under other regulations such as the Control of Asbestos Regulations 2012, the COSHH Regulations 2002, and the Control of Lead at Work Regulations 2002. Care is needed to ensure their safe disposal.

It is a legal requirement to create a classification description and waste transfer note before you send waste off-site for recycling or disposal.

[5] Zero Avoidable Waste in Construction, Construction Leadership Council

The Forge project set ambitious sustainability goals to become the UK's first net zero carbon commercial development recognised by the UK Green Building Council as aligning with its framework definition of net zero carbon in construction and operations. Also, it is the first office building to be built using the highly sustainable platform approach to design for manufacture and assembly (P-DfMA). This innovative method takes a manufacturing approach to the design and construction of a building, helping to standardise practices, creating time and carbon efficiencies for the project.

The scheme's innovative P-DfMA 'kit of parts' led approach with its focus on off-site manufacturing using repeatable and reusable parts, was designed to minimise the use of materials and reduce the amount of on-site and off-site waste generated. To assess how successful this, it became important to measure and record as accurately as possible the waste data to demonstrate what had been achieved.

To ensure that waste is managed proactively Landsec requires all its contractors to create Site Waste Management Plans (SWMPs) to record the results of waste audits and document the planned methods for managing waste. All sites are required to record and report on waste being generated during the construction process and have a duty to ensure that waste sent to landfill is minimised.

Landsec also committed to achieving a minimum BREEAM Excellent rating for the project. This required waste levels on-site to be closely monitored and documented to provide the evidence needed to secure the available credits for the waste measures within the BREEAM assessment of the building's sustainability credentials.
To meet this combination of legal obligations, innovation, and sustainability goals it was recognised at an early stage that digital tools would play an important role in collecting, recording, and analysing the materials delivered to and the waste removed from site.

To provide the rapid turnround of data needed to fulfil these goals a suite of software programmes was employed. These were selected jointly by Landsec and the Manufacturing and Assembly Manager (MAM), a Sir Robert McAlpine and Mace Joint Venture company created to manage the delivery of The Forge project.

This case study looks at how these digital tools were used to measure, monitor, report and analyse the waste streams arising from the on-site construction activities and how their deployment followed the seven-step framework.

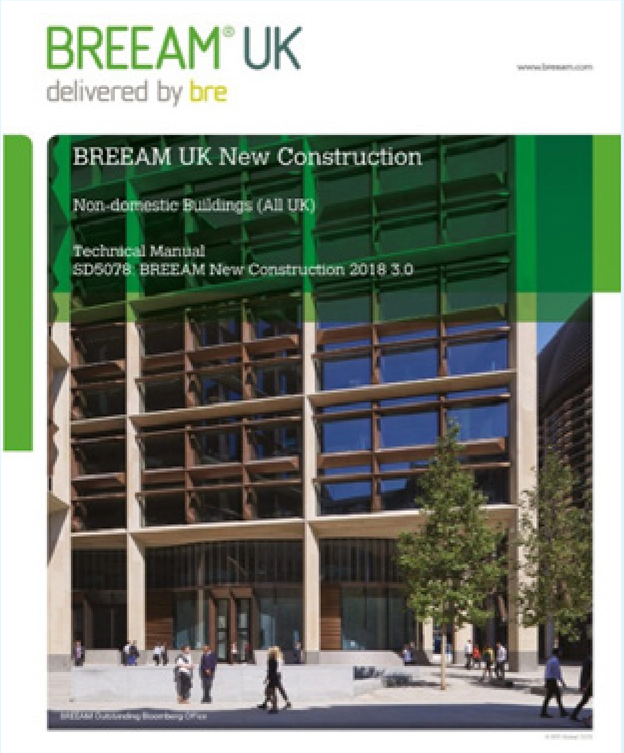


FIGURE 1 – BREEAM new construction certification

The processes applied on the project follows the seven-step framework.

STEP 1
ENGAGE

Although the regulatory and benchmarking requirements focus on waste generated on-site, Landsec's wider innovation and sustainability goals also encompassed the minimisation of off-site waste.

Landsec clearly defined their requirements in respect to waste at the outset of the project. All their sustainability goals are set out in the briefing pack for the design team and in the contractual documents used to engage the contractors and supply chain partners involved in the project.

The project was placed using a construction management form of contract which was managed by the MAM. All the trade contractors and key specialist suppliers were in direct contract with the client allowing close contact with the supply chain partners.

A number of key trade contractors were appointed at Stage 3 using pre-construction Service agreements (PCSAs) to allow the detailed design to be developed with the design team working in partnership with the supply chain specialists to ensure effective and efficient solutions, maximising the off-site manufacturing opportunity and minimising waste.

The benefit of this process in terms of lowering waste generation is probably best illustrated by the example set by specialist manufacturer Easi-space, a young SME company who were appointed to produce the temporary works props, shutters, brackets and integrated handrail system that made up reusable 'kit of parts' components used to form the superstructure of the two buildings on The Forge site.

A constant dialogue was set up between the designers – Bryden Wood and Easi-space to ensure that ease and efficiency of manufacturing was optimised, before the design progressed beyond the point where changes could be made:

- The brackets needed for the project were cut from sheets of mild steel with a laser cutter to a tolerance of 0.2mm. The computers controlling the process automatically 'nested' the individual pieces to reduce the wastage from off-cuts.
- By making small changes to the size/shape of the brackets to fit the raw steel coil sizes the waste from off-cuts could be significantly reduced. This level of information would not normally be available to the designers.
- The props were made from aluminium, through the early engagement process the box section could be cut to the exact length required in the tube factory prior to dispatch to Easi-space where their robotic welding facility created the final prop with zero waste or material recycling.
- The shutters dimensions were optimised around the sizes of available large format phenolic ply to reduce cutting these sheets to a minimum. (Which also improved the visual effect of the soffit when cast).
- The handrail cassettes were manufactured to a standardised design which enabled the components to be used repeatably between floors and across both buildings.

Continues...

The combination of early engagement, clear identification of the objectives and close collaboration with key supply chain partners maximised the opportunity to design out waste and design in efficiency in the construction process.

The approach was driven by the P-DfMA methodology. This together with requirements for the contractors to follow the waste hierarchy and engage with the digital tools being used to ensure good data capture and reporting were key to minimising waste.

STEP 2 DEFINE

To ensure that the objectives identified at the outset of the project are achieved in practice it is key to capture accurate actionable data as close to real time as possible. In waste management terms it is critically important to provide early warnings of any divergence from the expected outcomes, minimise the risk of failure to comply with regulatory requirements and provide actionable insights to improve the process.

A workshop was held with key stakeholders from the client, MAM, and design team to identify what data needed to be captured to fulfil the project's waste management requirements and meet the innovation and sustainability goals.

The following metrics were then defined:

- Non-hazardous construction waste efficiency measured in m3 or tonnes/100m2 gross internal floor area (GIA) – required to secure BREEAM Wst 01 waste management credits
- Project specific waste target of 3.2 tonnes/100m2 (GIA)
- Project specific stretch target of 1.9 tonnes/100m2 (GIA)
- Construction Leadership Council (CLC) benchmark measure m3 of waste / £100,000 of spend – productivity related measure endorsed by the Construction Productivity Taskforce
- Zero waste to landfill – to meet Landsec's sustainability target and to secure BREEAM credits
- Full compliance with regulatory requirements
- Off-site waste from component manufacture to be obtained from the supply chain wherever possible – no specific performance related metrics set

On most projects waste data arising from on-site activities is submitted by the trade contractors manually in arrears. The data is then checked and collated by sustainability managers working as part of the construction management team who then report. This process can take weeks and there are lots of opportunities for information to be incorrectly entered and for data to be lost.

When errors are discovered, the delays incurred in the process make it much more difficult to take corrective action and in the case of waste transfer notes incorrect information is a failure to meet the Duty of Care obligations and can lead to a Fixed Penalty Notice from the Environment Agency and the associated reputational damage that would entail.

During the project set-up phase, it was agreed that we would seek to use digital tools to collect and store the waste data and record and to look for other software technology solutions that could automate the data gathering and analysis.

STEP 3
IDENTIFY DATA

The following key data points were initially identified for collection for both the demolition and construction activities:

- Waste generated off-site in m3 or tonnes in the manufacture of the kit of parts (segregated by trade contractor/supplier and by the type and classification of material)
- Waste generated on-site in m3 or tonnes (segregated by trade contractor/supplier and by the type and classification of material)
- Hazardous waste in m3 or tonnes (segregated by trade contractor/supplier and by the type and classification of material)
- Waste transfer station used for on-site waste and distance transported
- Proportion of waste reused, recycled, or sent to landfill
- Feedback reporting in time to act
- Copies of waste transfer notes (preferably an electronic copy)
- Rolling measure of GIA created in m2
- Rolling measure of the value of work completed by trade contractor/supplier
- Monitor waste levels against BREEAM credit targets and Landsec's stretch waste reduction targets
- Compare NCR reports with waste levels for any correlations with re-works

STEP 4
IDENTIFY TECHNOLOGY

Each trade contractor was contractually responsible for managing the disposal of their own waste streams in accordance with the agreed site waste management plan. Copies of the waste transfer notes, and all other information required to meet statutory obligations and the client's reporting requirements were then submitted to the MAM for verification purposes.

Three technology tools were deployed to manage the on-site logistics and collate and verify the waste data.

DataScope – an online portal providing personnel access control to the site and dynamic management of all delivery and waste removal vehicles throughout the logistics life cycle.

Tracker Plus – an online end to end information management system to collect sustainability information and evidence for BREEAM

Qflow – automated data capture system using a combination of Artificial Intelligence AI and Machine Learning (ML). Images of delivery notes and waste transfer notes taken as vehicles arrive and leave site are automatically read by the AI. The information is digitised and uploaded into the Qflow App.

Continues...

Off-site waste records were collected manually and entered into spreadsheets. The information is uploaded into the project Power BI dashboard where it can be viewed in a visual format. However, obtaining this data proved to be challenging as many organisations did not have the information in a readily published form and it required the material suppliers to share information on their manufacturing processes and efficiency. We believe that this will prove easier in the future as more clients seek to better understand the wider impacts of their activities and demand more information from the supply chain particularly in respect of the embodied carbon in the materials they use, and the level of waste generated in the manufacturing processes.

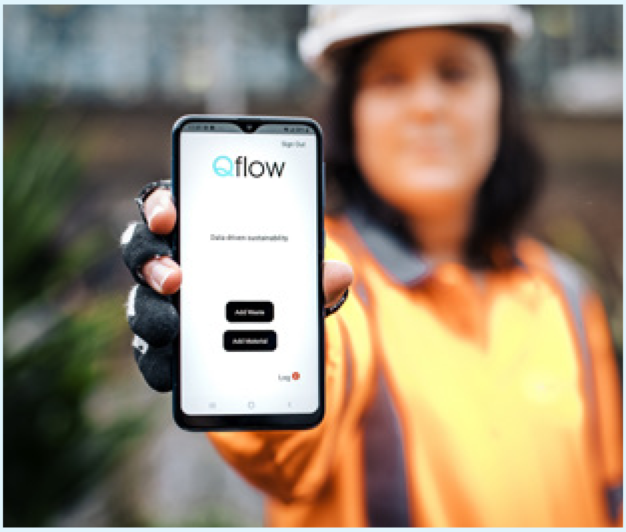


FIGURE 2 – New software using mobile app technology

STEP 5
COLLATE DATA

A data capture plan was then formulated by the MAM team with input from the client's project team and sustainability manager.

The key elements of the plan were as follows:

1. Use digital tools to collect and collate the data

DataScope system used to plan and manage vehicle movements to and from site:

- All delivery and waste removal lorries are booked onto the system by the Trade Contractors
- Bookings are made using the on-line App and each vehicle is allocated a date and time to come to site
- The MAM logistics team overview the process and resolve any prioritisation issues
- Vehicle access and egress to the site is controlled by the MAM's traffic marshals and the gate staff book the vehicles in and out on the App using a handheld portable computer

Tracker Plus used to collate all certified documentation associated with deliveries to and waste removed from site:

- Trade contractors access the App on-line to enter all the information required to meet the sustainability and statutory waste reporting requirements
- Electronic copies of the waste transfer notes uploaded
- Waste tonnage broken down by classification (as received from waste transfer stations) entered on-line
- Confirmation of zero waste to landfill confirmed
- Information is entered retrospectively up to a month after the delivery or waste collection occurred

Continues...

Qflow used to automatically capture the information contained in delivery notes and waste transfer notes when vehicles enter and exit site:

- App uploaded onto mobile devices
- Images of delivery notes and waste transfer notes taken by the MAM's gate staff
- All relevant information is then automatically extracted from the images by the AI software and loaded directly into the App in real-time
- Data quality checks carried out automatically and where necessary manually by the Qflow data managers
- Errors notified to the MAM and trade contractor or supplier by email the same day

The Qflow platform includes a range of dashboard analytics which provide insights into the waste data.

One example of this is the waste destination tracker shown in **Figure 3**.

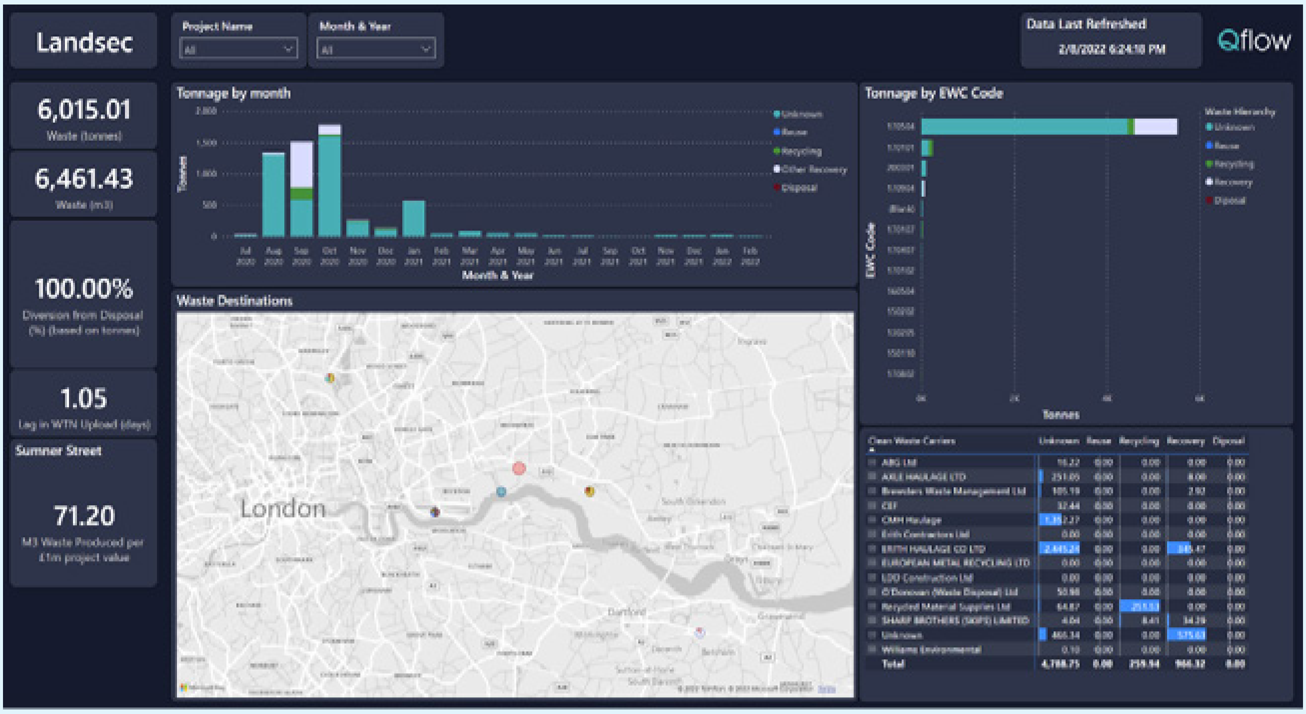


FIGURE 3 – Waste destination plotted for review

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2. MAM management role

- Provide a data manager responsible for the deployment of the digital tools and the provision of training and support to the construction package managers in their use
- Provide a sustainability manager to verify the sustainability information and waste transfer notes submitted
- Provision of a Power BI dashboard to display progress against the waste and sustainability targets and the metrics outlined in Step 2 in a visual format to inform the client and wider project team
- Ensure that all trade contractors have a clear understanding of their data reporting responsibilities and how to use the software platforms provided
- Train the logistics provider in the use of the DataScope and Qflow Apps at the site gates
- Act on any alerts for incorrect or incomplete data received from the Qflow App
- Collect, collate, and analyse off-site waste data
- Provide cost and area data for the benchmarking process

The combination of the use of the digital systems with a well-defined role and clear responsibilities for the site management team has proved to be very effective.

By using three different systems to capture data related to waste the team can use a triangulation technique to improve the accuracy of the information being gathered. For example, if the site gate team failed to record a waste transfer note on Qflow there would be a mismatch with the vehicle movement record on DataScope or vice versa if Qflow had a record of a waste removal action which had not been logged on DataScope.

The MAM sustainability manager is then able to follow up with the trade contractor or supplier and ensure that any data missed at the gate has been entered on Tracker Plus. Similarly, if a record has been entered on Qflow but is not on Tracker Plus these highlights to the team an incomplete data set in the manual record submissions entered at the end of the month.

STEP 6
MEASURE & ANALYSE

Given the reliance on digital tools to capture, record and analyse the waste data it was important to ensure that their performance and the outputs provided were monitored closely. In addition to the direct day to day management oversight provided by the MAM's data manager a digital steering group was formed with representatives from the client, designers Bryden Wood and a research team from Cambridge University to review the data gathering processes and analyse the results.

The primary focus was to identify productivity related insights and ensure that good quality data records were available to comply with statutory requirements and produce the sustainability metrics required by the client. However, having access to near to real-time delivery and waste removal data from the Qflow App and the greater level of detail captured by the AI together with the platforms analytic capabilities provided a number of other benefits:

- Same day alerts for incorrect and incomplete data allowed for speedy follow up action
- Detailed analysis of waste destination data allowed the MAM to direct the trade contractors to use the most effective transfer stations
- Vehicle mileage tracking provided actionable insights for the MAM and client team to work with the trade contractors and suppliers to reduce the carbon footprint of the site
- The Qflow App has an extensive dashboard - another example of the outputs available is shown in **Figure 4** below

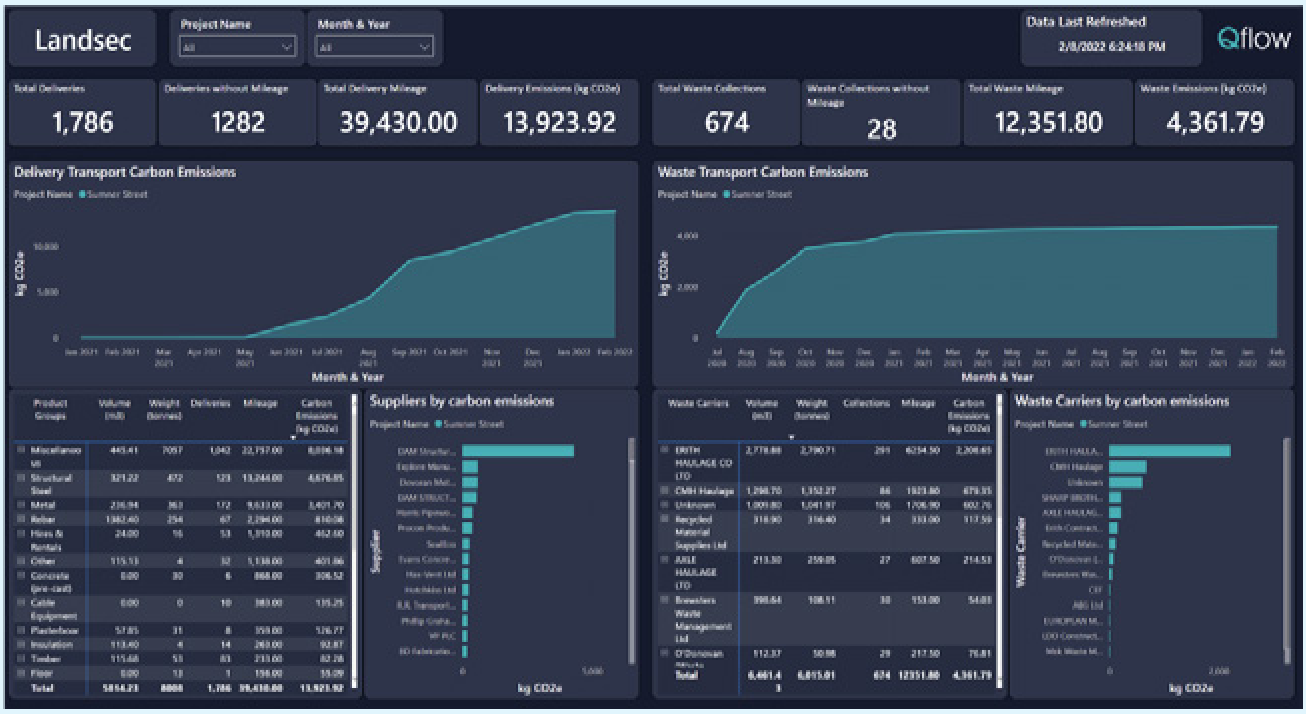

FIGURE 4 – Qflow project analytics dashboard

Continues...

All the waste data gathered by the digital tools is in the process of being analysed by the team and the high-level work in progress results against the benchmark metrics are being shared with the wider team through the Power BI dashboard. The team is grateful for the support of the Cambridge University researchers who have assisted in the analysis of the data and development of the project level metrics bringing academic rigour to the process and independent analysis of the results.

The overall waste target set for the project by Landsec was an ambitious 3.2 tonnes/100m2 of gross internal area with zero waste to landfill, and progress is being measured against these targets. The project is still under construction so the final metrics will not be available until the construction is complete. Once collated, data relating to the industry level CLC waste benchmark adopted by the Construction Productivity Taskforce to drive productivity improvements across the industry will be uploaded onto the Construction Data Trust Platform.

Is the boat going faster?

Not necessarily faster in this case but the boat is certainly enjoying plain sailing because of this process, due to the clarity and accuracy of the data gathering, the quality of the data collected and the near to real-time analytics providing actionable insights.

STEP 7
IMPROVE & FEEDBACK

On-going lessons learned capture sessions are being held with the sustainability team which because of the project's use of P-DfMA (Platform Design for Manufacture and Assembly) techniques allows these learnings to be fed back into the model design as part of a continuous improvement process. The benefits from updating and reusing previous designs and engineering solutions to optimise waste levels wherever generated, can then be baked into future designs.

The completeness and quality of the data gathered and the ability to act quickly when issues arise is key to a successful outcome. The team was not able to find one software tool which was able to carry out all the tasks identified and therefore three different digital tools were deployed which in part overlapped with each other. This proved advantageous in terms of data quality and verification but did complicate data capture at the gate.

To ensure alignment and maximum value from utilising these tools, the project team have worked closely with Qflow and the other tool providers to achieve significant milestones by linking each system through a series of integrations using Application Programming Interfaces (APIs). First, between Datascope and Qflow, and then between Qflow and TrackerPlus and Power BI through using the Qflow API. This meant that the project team were able to improve the workflow efficiency for capturing and reporting this data, whilst maximising the value-add of each independent software tool.

The feedback from the logistics team was that:

- The gate staff found the need to use two different Apps to record deliveries and waste removal was unwieldy.
- Staff needed to enter data into the DataScope system on the portable computer and then take a picture of delivery notes and waste transfer notes on their personal mobile phones.
- Some staff were also unwilling to download the Qflow App onto their personal phones.

Continues...

The MAM sustainability manager required the Qflow data to be transferred into the Tracker Plus platform where it could be collated with other information required for the BREEAM and sustainability reporting. This initially required a manual upload of CSV files. The MAM data manager also had to upload data from all the three tools into the Power BI dashboard. This added further manual processes with the opportunity for errors to be introduced. To improve the process in the spirit of collaboration all three software companies agreed to work together to develop API links to transfer information between the different platforms.

The focus of the Tracker Plus system is to collate information required for the BREEAM assessment process in one location, allowing the project team to review the progress being made in real time. At The Forge it is also being used to collect and store other sustainability information needed to track progress across a range of other KPI targets. The information in Tracker Plus is gathered from multiple sources, most of which must be entered manually.

The Qflow/Tracker Plus API enables the information abstracted from the site delivery and waste transfer notes by the Qflow AI platform to be automatically uploaded into Tracker Plus.

The API integration between DataScope and Qflow is aimed at simplifying the process for the gate team, so they only need to be familiar with one software app and use one device. The touch pad used to access the DataScope App has a camera facility so it can be used to photograph the delivery and waste transfer notes while the deliveries are logged onto the DataScope system. The API then allows the images to be automatically uploaded into the Qflow platform where the AI can then read and download the information from the delivery and waste transfer notes.

Qflow have also developed an API link to work with Power BI so that the advanced analytics outputs provided in the App can be easily uploaded by the MAM data manager into the project dashboard for the high-level monthly reporting.

This level of collaboration between the different organisations was unexpected but is proving valuable. For a period, the API links were operated in parallel with the manual data transfer for a trial period but in January 2022 the systems were switched over to operate automatically. Hopefully the level of cooperation we have seen between this companies will set a good example for others going forward.

The results from this study have been shared with the project team members and external stakeholders including UKRI Innovate UK (who selected The Forge as a Demonstrator Project for the Transforming Construction Challenge programme), Cambridge University, and the Construction Data Trust.

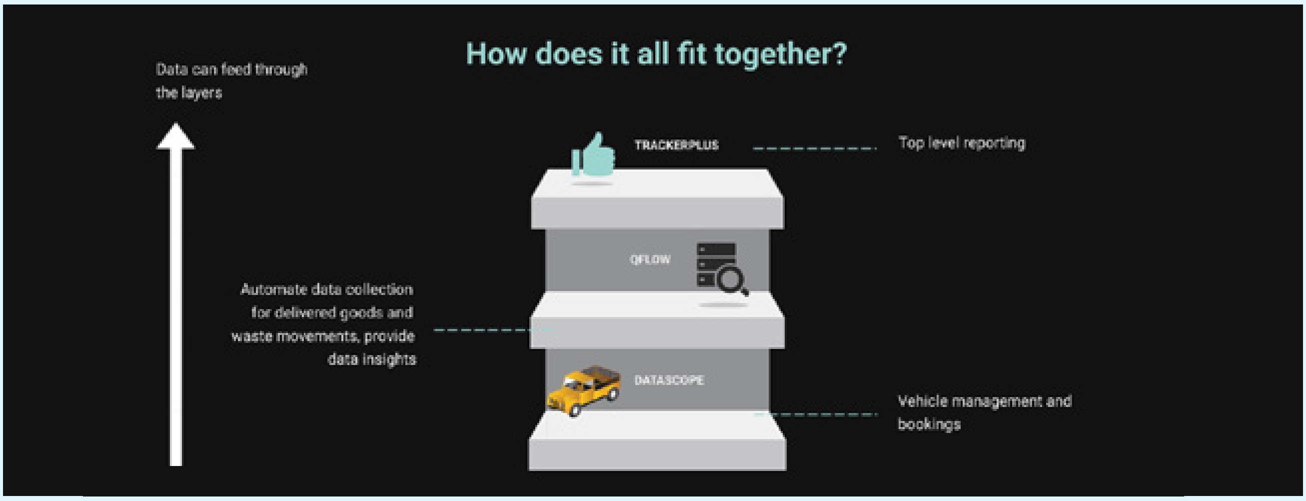

FIGURE 5 – Software integration between three suppliers

Case Study #4

Norton Folgate
Tower Crane Utilisation

Location
Central London, UK

Client
British Land

Main Contractor
Skanska

Architect
AHMM, Stanton Williams, MoCo, DSDHA

Supplier
Select Plant Hire

Works Description
Maximising tower crane utilisation and productivity across the site using IoT sensors and telematics technologies

Background

Tower cranes are one of the most expensive elements of plant used on building projects, and especially high-rise commercial offices where their use is an essential part of the construction sequence. Ensuring that they are used efficiently and to maximum productivity has a direct, and positive, impact on overall project progress.

However, when they are used inefficiently and underutilised, they can result in significant additional cost to the project and have a negative impact on project progress.

The Norton Folgate project required four tower cranes at its peak, all of which had to be carefully planned in terms of their location and in terms of daily utilisation across the various contractors requiring use of the cranes each day, to ensure they can be used at an optimum productivity level.

This study looked at the use of IoT sensors and crane telematics to develop a means of monitoring and tracking tower crane utilisation in real time, so that insights into inefficient use and underutilisation of the crane can be identified early and productivity improvement actions taken by the project team.

Crane telematics are built-in sensors attached to the crane that allow the movement of the crane to be tracked in real time. They can track a multitude of data sets, including crane location and height, slewing times, lifting times and weights, wind speed and overall utilisation.

The data can be captured and analysed in real time to show usage trends over a day, week, month, or longer periods of time.

The processes applied on the project follows the seven-step framework.

STEP 1
ENGAGE

As part of the main works procurement process, Select Plant Hire was appointed to provide the tower crane requirement across the Norton Folgate project.

British Land, Skanska and Select Plant Hire understand the importance of good tower crane utilisation on a project like Norton Folgate and the crane related issues that can disrupt productivity and production across the project, such as:

- Underutilisation on sites with multiple tower cranes having to wait for other cranes to slew
- Crane not always available when needed by a subcontractor
- Actual crane allocation not keeping to planned allocation schedule
- Knock-on effects of crane underutilisation, e.g., schedule delays because work is pushed back, having to re-align work because the crane has already been allocated to another sub-contractor
- Inefficiency in the pit lane due to late or congested deliveries
- Late & early deliveries to site disrupting planned crane utilisation
- Crane winded off due to high wind speeds
- Crane breakdowns and/or planned maintenance

It was also clear that only manual methods were being used by the project team to monitor crane usage across the site, in terms of a spreadsheet/paper based planned and actual allocation schedule, and verbal communication and feedback from the site team as to the issues being encountered each day.

From further discussions with the site team, it was clear that being able to track tower crane usage in real time would enable the project team to be made aware early of disruptors and productivity blockers, and thereby take action to rectify and improve productivity.

British Land, Skanska and Select Plant Hire were keen to explore how new technologies can help improve productivity across construction operations, and from early discussions Select Plant Hire offered to supply their cranes with built in crane telematics sensors for the crane usage to be tracked in real time.

A productivity study was agreed to monitor the use and benefits of crane telematics across the tower cranes on the site.

STEP 2
DEFINE

Over the course of number of workshops and early trials of the telematics data, Skanska and Select Plant Hire agreed to capture the following metrics direct from the telematics sensors. This data was collected daily and reported to the site team on a weekly basis using a Power BI format:

- Operational status (i.e., active, inactive, winded off, planned maintenance, technical fault)
- Crane activity logged per hour
- Wind Speed
- SMIE data (the time a crane is waiting for another to slew)
- Lifts by weight, height, and total number
- Lift time and time between lifts

STEP 3
IDENTIFY DATA

The data points needed to measure these metrics were chosen automatically from the telematic data being captured on each of the four tower cranes used across the site.

STEP 4
IDENTIFY TECHNOLOGY

In addition to the telematics sensors, the study also required the establishment of a data capture, storage and analysis platform using MS Azure and a Power BI file to present the data in real time.

STEP 5
COLLATE DATA

A data capture plan was formulated by the Skanska and Select Plant Hire teams, combining the data points identified in Steps 2 and 3 with the appropriate measurement method identified in Step 4.

This then allowed the data collection process to be streamlined from data collected automatically on site, consolidated, and analysed in a central database, and presented in a Power BI format.

The presented data was then reviewed and analysed by the project team on a daily, weekly, and monthly basis to identify trends and insights into what the data was showing.

STEP 6
MEASURE & ANALYSE

A typical weekly report from the telematics data is shown in **Figure 1** on the next page, which shows the breadth and depth of data being recorded automatically and in real time by the crane telematics.

In addition, the data can record exactly how and where a tower crane operated over the course of a day, which was found to be very useful on a multi-crane site such as Norton Folgate to see the interaction of the cranes.

The captured data and metrics provided a number of insights to the project team, including:

- Providing greater transparency and real time monitoring of crane operations
- Identifying crane waiting time and delays between lifts – highlighting need for better forward lift planning
- Identifying most efficient period for crane utilisation was during the morning and early afternoon (see **Figure 3** below) – enabling most critical tasks to be planned in morning and less critical in late afternoon
- Extended operating hours was shown to have a negative impact on productivity output
- Understanding SMIE data (i.e., when a crane is waiting on another crane to slew) can have a big impact on crane location positioning

The study is being extended to develop a means of linking the crane data to specific contractor usage, so that planned verses actual crane utilisation can be more readily monitored and acted upon.

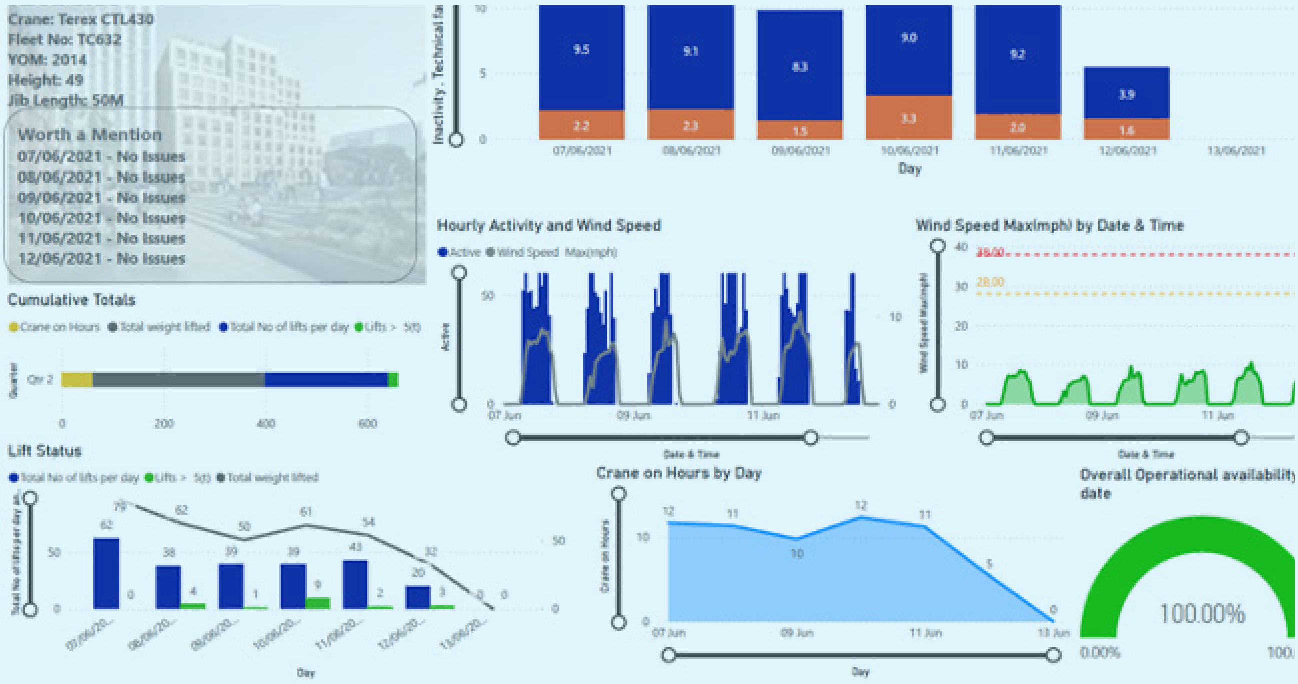

FIGURE1 – Typical Tower Crane Utilisation Report

FIGURE 2 – Tower Crane interaction by operations

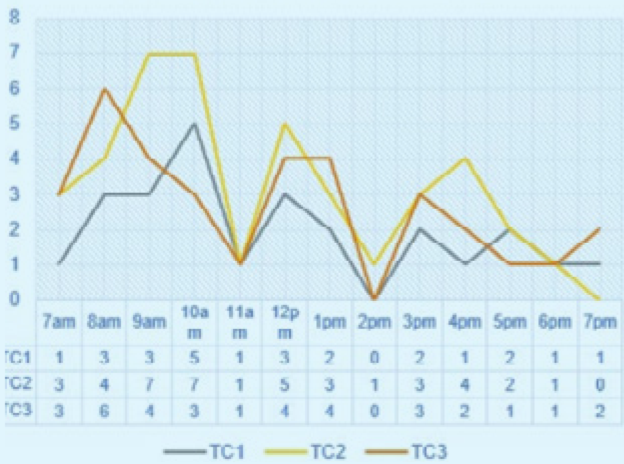

FIGURE 3 – Tower crane lifts per hour over the course of a day

Is the boat going faster?

Yes, telematic sensors – whether used on tower cranes or other plant and equipment (e.g., hoists and other mobile plant) - enables productivity insights to be identified and actions taken to improve crane usage and logistics – thereby improving productivity. The wide range of data that can be captured and reported in real time, enables wasted time and activities to be better identified and thereby allowing operations to progress more efficiently.

As the data capture and analysis process improves, there is the opportunity to use the data to identify optimum crane solutions for a given site through the use of artificial intelligence (AI) techniques.

STEP 7
IMPROVE & FEEDBACK

This productivity study has shown the huge potential that telematics must help improve productivity across the construction industry, and their use across construction will grow over the coming years. Not just for their use in tower cranes, but also for a multitude of other plant and equipment used across construction, such as other mobile plant and hoists.

From this study, the main learning and feedback to be used on future projects were:

- Telematic data gives us greater insight on how cranes are operating than previously available
- They give us data and evidence to back up discussions and activities on site (i.e., a source of truth)
- Telematics enables much greater transparency in the way cranes are utilised allowing identification of inefficiencies in crane location planning, crane utilisation, site logistics and deliveries
- Telematics should be extended to hoist operations, to better understand hoist utilisation and logistics, and identifying where there is spare capacity and how this spare capacity could be best used.

The use of telematics is continuing on Norton Folgate and other Skanska/Select Plant Hire sites, to explore the use and benefits of this technology further.

One key requirement that resulted from this study is the need to be able to track which contractor is using the crane to compare against planned utilisation and gain greater understanding on how efficiently cranes are utilised (i.e., planned vs actual crane utilisation) – this work is currently in progress and will form an update to this case study later in 2022.

What have we learned? Summary findings and next steps

We believe that the practical guidance, seven-step framework and case study examples presented in this document, on how to measure and analyse construction site productivity, provides a great platform for the industry to build from.

The two pilot projects used by the Construction Productivity Taskforce to test the framework have demonstrated its effectiveness in identifying productivity improvement opportunities and actionable insights at a project level and how through the sharing of data it is possible to drive improvements across multiple projects and help to create performance benchmarks for the construction industry.

The establishment of the Construction Data Trust which has been supported by the Taskforce will be key to the development of the performance benchmarks.

Pilot Projects

The continuing work on the pilot projects is already showing positive signs that the proposed framework together with a standardised approach to measurement and performance metrics has the potential to establish an agreed construction site productivity improvement framework for the wider construction industry.

Going forward, the Taskforce is continuing the work on the pilot projects to further test and evaluate all five of the high-level industry productivity metrics it has proposed: productivity, waste generated, pre-manufactured value (PMV), right first time and tool time. We also plan to expand our focus to other key drivers of productivity including, but not limited to, 'designing for productivity' and 'training for productivity'.

Our intention is that this framework will be a living document which is continually updated as the approach is adopted and used by Taskforce members and other organisations active in the construction sector. We are already planning to include further case studies from the pilot projects in an update to this framework towards the end of 2022.

Acknowledgements

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