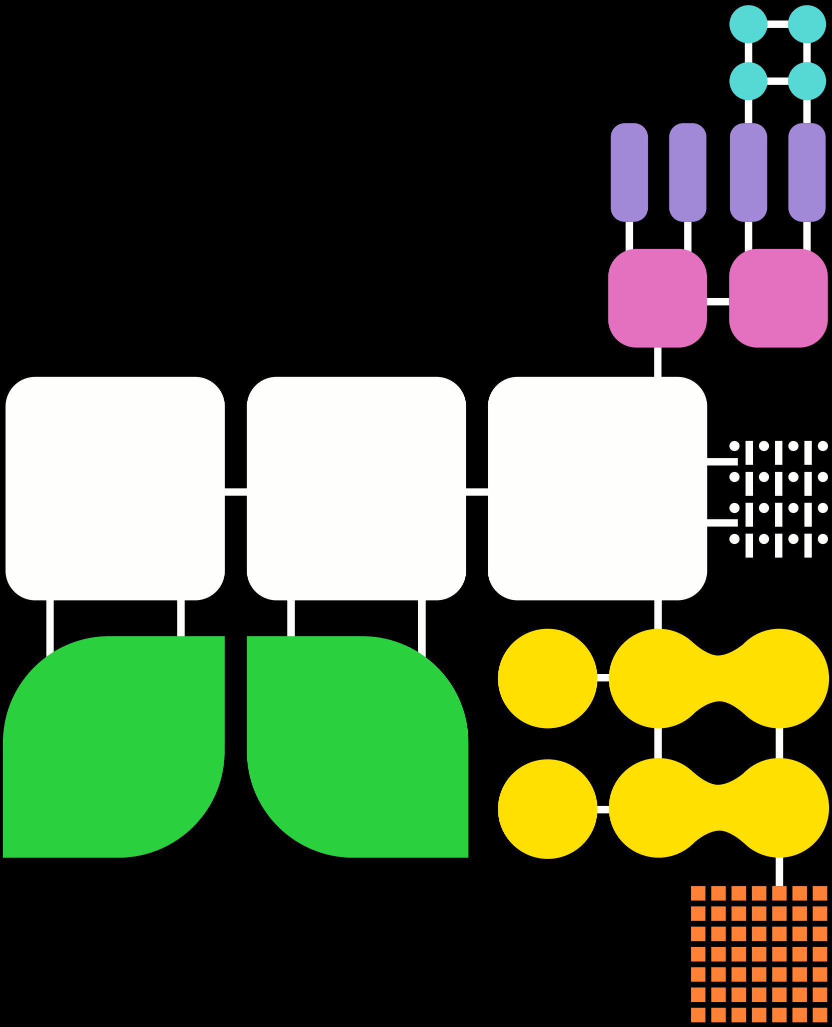
Delivery Platforms for Government Assets

Creating a marketplace for manufactured spaces



Bryden Wood

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Foreword

Keith Waller,
Programme Director –
Construction
Innovation Hub

I'm sure many of you will have seen this book, or extracts from it, over the past five years. I clearly remember sitting with Jaimie Johnston in Bryden Wood's London office at the start of 2017, when the early thinking behind *Transforming Infrastructure Performance* was developing in parallel with the content of this book.* Government at the time was thinking about how to improve whole-life performance and boost productivity across its infrastructure programme. This wasn't about how to be cheaper, it was about being smarter and better.

A number of government departments and agencies were exploring Design for Manufacture and Assembly (DfMA) options and considering the benefits a platform approach might bring to their programmes. The Ministry of Justice (MOJ) had developed a platform approach for their Prison Estates Transformation Programme (PETP), but at this time neither the thinking nor approach were widely understood. And, if we are honest, the potential benefits were not clear. We all had a feeling this would speed production, reduce waste, improve quality and more. But we couldn't quantify these benefits, nor demonstrate whether the thinking behind PETP would be easily scalable across other projects and programmes.

So back at that meeting in early 2017, Bryden Wood, the Manufacturing Technology Centre (MTC), PETP and colleagues from the Infrastructure and Projects Authority (IPA) convened to consider what a wider version of the PETP platforms approach to DfMA would look like, to solidify the thinking started by PETP. At the end of that meeting we agreed we would develop a longform write-up that would disseminate this thinking and approach. And, recognising how integral digital aspects were, we recommended it was developed with the Centre for Digital Built Britain.

The first iteration of this document was launched in May 2017 at the Construction Leadership Conference. Its purpose was to build awareness and understanding, not to act as a detailed "how to" guide. But its impact has been much wider. It has helped inform and shape policy. There are strong synergies with IPA's *Transforming Infrastructure Performance,* its links with the 2017 Autumn Budget announcement of a "presumption in favour of offsite" and, of course, the ambition set out in the 2018 Construction Sector Deal.

**Transforming Infrastructure Performance*, published in December 2017, outlined the UK government's plan to improve the delivery and performance of infrastructure and boost construction sector productivity.

This book has followed me from writing *Transforming Infrastructure Performance* at IPA, to delivering the sector deal as the Programme Director of the Construction Innovation Hub. Platforms form a central plank of the Hub's programme. We are partnering with many leading industry players to create a platform ecosystem, and our work continues to be shaped by the thinking in this book.

Government too remains actively engaged, with ever-more departments looking to embed platform approaches. And policy makers continue to echo its ethos, from IPA's response to its *Proposal for a New Approach to Building: Call for Evidence* to the government's *Construction Playbook* in December 2020.

Since that first meeting in 2017, there has been great progress. But there is much still to do, and not just about developing the technical solutions. It is crucial we continue to work together to create the right delivery environment that enables innovative solutions to thrive. We need to demonstrate how this approach supports our shared ambition for greater safety, quality and productivity, as well as helping accelerate our path to net-zero. And of course, to deliver it at scale, we need to build capability and capacity in our designers, manufacturers and contractors.

I remain confident that change will happen, perhaps faster than many of us have dared to hope. The momentum driving a transformation in our sector continues to build. Long may it continue.

Introduction

Jaimie Johnston MBE, Director, Head of Global Systems, Bryden Wood

When Keith Waller asked us at Bryden Wood to detail the platform approach in a longform write-up, we approached this as the creation of a briefing document of sorts – one that could be distributed as an introduction to the approach.

What we witnessed was that this ‘document’ took on a life of its own. Word-of-mouth distribution and downloads extended more widely across industry than we had ever expected: from government, to private sector clients, to university professors, students and manufacturers, in the United Kingdom and beyond.

Somewhere along its journey, it transcended its role as a briefing document to become a book, an object of practical use with a lasting impact. It was therefore time that we turn it into one – one that is better suited to its users and fit for the wider purpose it has assumed.

Changes to the content are minor, but with some small text edits and a reframing of the layout, we have hopefully delivered a book that is easier to digest, reference and can better underpin the thinking behind platforms as it develops apace. We hope you find it of value.

Context

Government will use the scale of its construction portfolio to help transform the market for creating high-performing assets, which improve their service for users, citizens and society while building a highly skilled and productive workforce.

It will improve the performance of assets towards international benchmarks, enhancing quality, lowering carbon and increasing whole-life value.

It will develop advanced manufacturing capability, products and services in the United Kingdom that could be exported globally.

A marketplace for manufactured spaces

Government spends around £10 billion per annum buying buildings, and more on maintaining and operating its existing stock – across schools, hospitals, prisons, offices and social housing. However, the multiplicity of departments, agencies and arms-length bodies that specify, procure and operate these facilities means that there is a wide range of solutions deployed to solve similar problems.

In addition, government buys its buildings from a construction industry that is fragmented, wasteful, unpredictable and unproductive.

At the simplest level, government buildings are made up of a series of spaces with different functions, customised layouts and physical systems that create different boundaries between spaces, with different external appearances, at different scales. For example, a typical secondary school is made up of a series of 55m² classrooms, plus common facilities (assembly hall, staff room, canteen etc.). The size is dependent on the number of pupils, but the function is broadly similar.

> Government will use the scale of its construction portfolio to help transform the market

However, currently we don't always ask for this information in the right way, and we often ask the wrong people to do things for us.

This book presents the opportunities to create a new paradigm by adopting the same principles which have transformed the automotive and aerospace industries.

The aim is to establish appropriate levels of standardisation in

- Design of both the 'spaces' and the 'physical systems' that bound them;
- Procurement;
- Manufacture;
- Assembly.

This strategy builds on the increasingly wide acceptance that a DfMA approach in construction yields significant benefits in terms of time and cost savings, while increasing productivity, quality and safety.*

This book describes the strategic adoption of DfMA in a coordinated and consistent way across the government estate, setting out the following:

- The benefits of DfMA
- The briefing and design process that facilitates the adoption of standardised solutions
- Necessary characteristics of a standardised set of platforms
- Methods of asset assembly that maximise the benefits of an industrialised approach

*The 'Context' section of this document refers to a number of recent publications containing supporting evidence and advocating the adoption of such an approach. See the 'Dossier' section at the end of this book (236-46) for a short literature review of these publications.

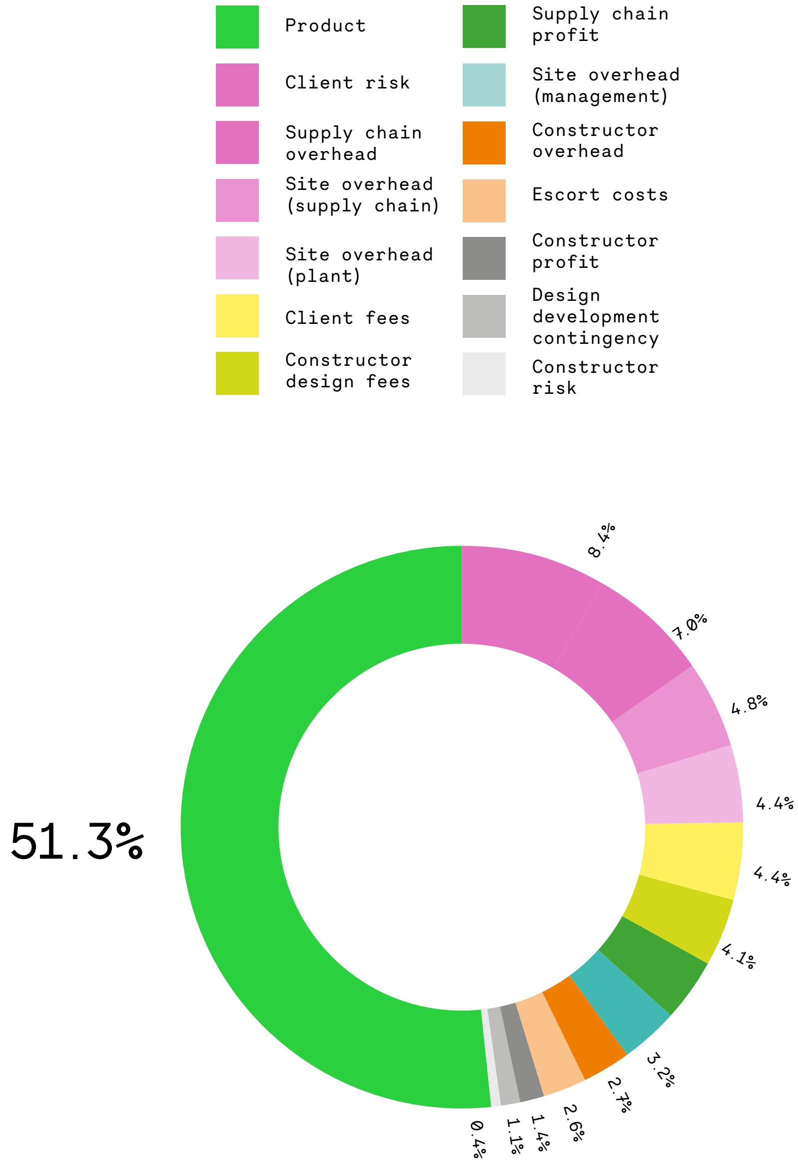
The problem

A recent government analysis on projects carried out under their construction framework shows that of the construction sum of a typical project, only about half ends up as residual value in the final product. The remainder is spent on

- Risk inherent in the design and construction method;
- Fees for the various designers involved;
- Profit and overheads for the various parties involved.

Of every £1 spent, just over 51% is retained in residual asset value

Government project cost analysis



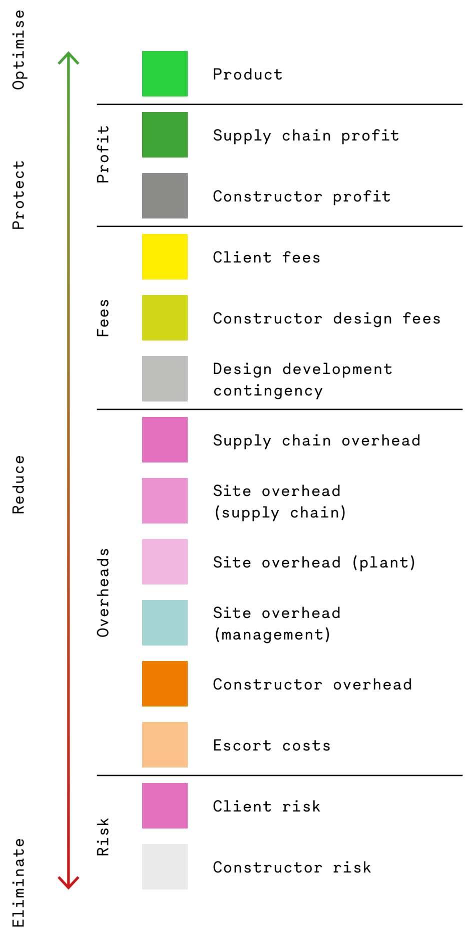
Source: Internal government construction analysis, 2017.

Typical value-engineering strategies intended to reduce cost are often rather exercises in reducing specification or compromising the design vision. Other cost-reduction exercises focus on the supply chain, where savings of a few per cent may be achieved by squeezing suppliers.

Critical to increasing residual asset value is the elimination or reduction of non-value-adding costs including

- Fees, through a centralised, standardised design;
- Overheads, by procuring centrally;
- Risk for clients, repeatability of design and delivery, simulation, prototyping etc.

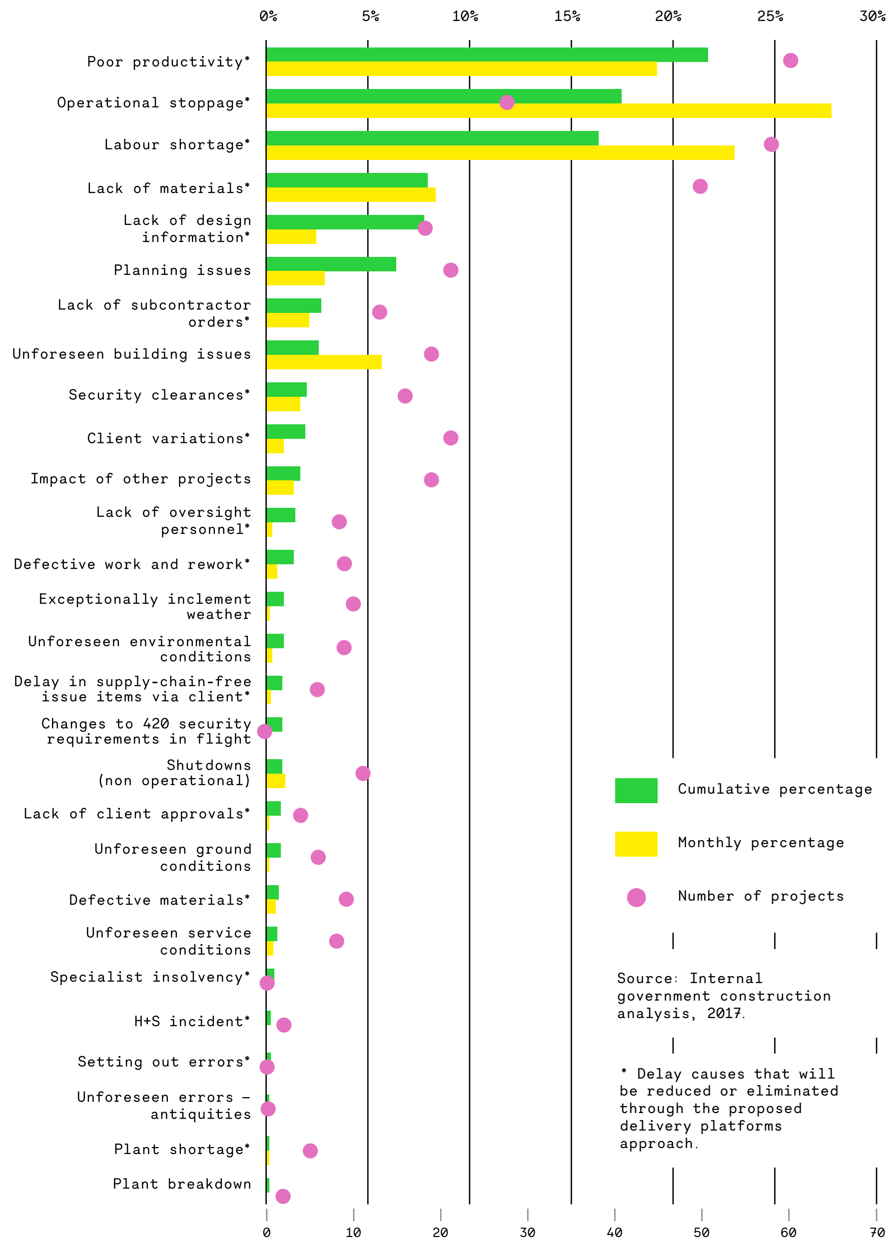
Proposed value engineering approach



Project performance analysis found that the most significant causes of project delays and cost increases, accounting for ~30%, are

- Poor productivity;
- Operational stoppage;
- Labour shortage;
- Lack of materials;
- Lack of design information.

Reasons for project delays



Strategic aims

The scale of government procurement in buildings and infrastructure warrants a more informed strategy, to move beyond current industry problems by truly understanding value and seeking to

- Design solutions that deliver the maximum functionality for the minimum whole-life cost;
- Develop standard, repeatable solutions that increase quality and certainty of delivery;
- Engage the supply chain in a way that facilitates continual improvement rather than constant reinvention;
- Protect supplier profit and overhead, as these are positive aspects that support the wider economy and ensure that the project is seen as attractive to potential suppliers in a highly competitive market;
- Focus the time and effort of designers on the bespoke elements of projects, while optimising the use of digital tools and standardisation to automate the production of repetitious information, which is often resource intensive but adds little value;
- Streamline the delivery process to create a high volume of quality information, which could reduce or redistribute design fees while still providing profitable and creatively challenging work;
- Focus on reducing the proportion of construction cost and programme that has no residual value but is related to risk, rework and waste.

The overall aim would be to improve productivity across the design, delivery and maintenance of the government estate by

- Adopting best practice in design, procurement, manufacture, assembly and operation;
- Reducing rework and duplication of effort;
- Minimising waste and risk.

Rigorously seeking to find the most efficient way of delivering a project inevitably reduces the resources required (whether measured in carbon, cost, time, waste or labour) while increasing positive aspects (health and safety, certainty, quality, morale, reputation and competitiveness).

The approach therefore inherently seeks to

- Ensure maximum integration of design disciplines;
- Reduce duplication of effort;
- Drive down total costs;
- Engage with the supply chain in a planned and timely fashion, drawing on expertise and innovation where it adds value;
- Facilitate waste reduction through strategic and collaborative procurement using common components, materials and construction processes;
- Blend highly standardised, mass customisable and bespoke elements together to create solutions that are finely tuned to suit the context;
- Optimise the use of traditional, modular, flat-pack and system-build elements where they add the most value, e.g. to maximise off-site labour where appropriate and improve the efficiency of in situ construction;
- Facilitate flexibility through the creation of standard components which can (through interchanging elements, reconfiguring or extending facilities) be readily adapted to future changes in policy, regulations, etc. and eventually disassembled.

Between 2013 and 2017, HM Government published a range of documents outlining its targets and aspirations. The relevant summary insights are outlined below.

Construction 2025

- 33% reduction in both the initial cost of construction and the whole-life cost of assets
- 50% reduction in the overall time from inception to completion for new build and refurbished assets
- 50% reduction in greenhouse gas emissions in the built environment
- 50% reduction in the trade gap between total exports and total imports for construction products and materials

Fixing the foundations

The government's framework for raising productivity is built on two pillars:

- Encouraging long-term investment in economic capital, including infrastructure, skills and knowledge
- Promoting a dynamic economy that encourages innovation and helps resources flow to their most productive use

Apprenticeships are a key part of some of the most successful skill systems across the world. Many countries offer people (young people in particular) a high-quality training route where they develop skills tailored to a particular sector or industry, and earn while they learn.

Building our industrial strategy

The documents outline ten points crucial to bolstering industrial strategy (those in bold are most relevant to this book):

- Investing in science, research and innovation
- **Developing skills**
- **Upgrading infrastructure**
- Supporting businesses to start and grow
- **Improving procurement**
- Encouraging trade and inward investment
- Delivering affordable energy and clean growth
- **Cultivating world-leading sectors**
- **Driving growth across the whole country**
- Creating the right institutions to bring together sectors and places

Benefits of Design for Manufacture and Assembly

What is DfMA?

DfMA is an approach which allows designers to maximise value for clients, maintain control over the delivery of their designs and facilitate the adoption of emerging methods, materials and technologies in construction best practice. It is important to stress that DfMA is a design activity driven by an understanding of a client's requirements, not a bolt-on product.

DfMA encompasses a wide spectrum of tools and technologies, but the underlying driver is to break the relationship that traditionally exists between time, cost and quality in the construction industry by reducing or eliminating waste or any activity that does not add value to the client, designer or supply chain. Typical benefits are summarised here.

It is important to mention that adopting a standardised or manufacturing approach does not necessarily imply the use of standard, manufactured elements; it may simply mean benefiting from some of the approaches that the manufacturing industry takes to logistics, just-in-time delivery, standardised interfaces, design rationalisation and optimisation in seeking to achieve high rates of productivity.

Common manifestations of DfMA include the use of prefabrication and off-site manufacture in the construction phase. This includes modular or volumetric units, flat-pack or panelised systems and component-based construction systems.

These approaches reduce the time designers need to spend on documentation, leaving more time for them to focus on what really matters: ideas and outcomes.

DfMA approaches support a broad range of architectural outcomes

In the same way that past architectural movements have been based on a form of technology (e.g. steel frames), if data and manufacturing now lead design, what would – or should – it look like?

Benefits of DfMA

Quality

- Factory quality-assurance and testing procedures reduce on-site commissioning and defect rectification, improving reworking and snagging by up to 70%.
- Adoption of the Advanced Product Quality Planning (APQP) methodology increases competitiveness, saves both time and money, reduces waste, manages risk and ensures customer satisfaction.
- APQP methodology ensures that designs are fit for purpose, that non-conforming products do not reach the client site and that the safety and reliability of the finished product are not compromised.

Programme

- Taking items off the critical path reduces time on site.
- Fewer deliveries, trades and activities to plan increases certainty in the programme.
- Installation and assembly (as opposed to construction) sequences are more capable of precise execution.
- DfMA substantially mitigates issues of lack of design information, which typically account for up to 8% of delays on site.

Health and safety

- Limiting number of hours on site reduces incidents by 80%.
- Reduced traffic movements to and from sites leads to improved neighbourhood road safety – up to 20% reduction in road accident data within 0.5km of site.
- DfMA assists neighbourhood consultation and reduces disturbance due to construction.

Labour

- Reduced hours and increased productivity improve efficiency (poor productivity and manpower shortage account for up to 37% of on-site delays).
- The productivity of factory staff is 80% relative to 20% productivity of on-site workers, who typically cost up to twice as much as factory personnel.

Waste

- DfMA components allow waste reduction through better stock control; research data suggests DfMA reduces site waste by 70 to 90%.
- Fewer traffic movements to and from site reduces neighbourhood pollution and congestion by up to 20%.
- Reduced site labour results in up to 50% saving in renting, heating and lighting of temporary site accommodation.
- Improved performance-in-use of environmental controls (better assembly and factory-based commissioning) results in up to 30% reduction in carbon dioxide.

Sources: Nigel Fraser et al., *An Offsite Guide for the Building and Engineering Services Sector* (London: Building Engineering Services Association, 2015); and internal government construction analysis, 2017.

Characteristics of hybrid DfMA solutions

Speed

- Rapid on-site installation if connections and interfaces are pre-planned.
- Requires more work than pre-finished volumetric solutions.
- Requires fit-out and finishing work to take place on site.
- Areas less protected in panelised solutions than fully volumetric systems; programme activities cannot be overlapped to the same extent.

Delivery

- Requires fewer operatives on site compared to traditional methods.
- Can reduce the level of skill required on site.
- Requires more logistical control than volumetric, as there are more units to control.
- Introduces more operations on site (e.g. more crane lifts) than pre-finished volumetric.
- Can use low-skilled operatives to assemble the units.
- Allows a wide supply chain by splitting elements into more components.

Carbon

- Logistically efficient, as they can be stacked or packed for transport.
- Significant reductions in waste.

Cost

- Lower costs due to speed efficiencies.

Circle Hospital, Reading

- 20% reduction in overall programme
- 28% reduction in cost
- 79% of components were standardised

Heathrow Terminal 3 Temporary Flight Connection Centre

- 38% reduction in overall programme
- 75% of work taken off site
- 28% reduction in cost

GlaxoSmithKline ‘Factory in a Box’

- 60% reduction in overall programme
- 75% reduction in labour
- Cost neutral (achieves world-class standards for the cost of traditional construction in Africa)

EcoCanopy Primary School Projects

- 50% reduction in overall programme
- 90% work taken off site
- 40% reduction in cost
- 3% waste created (versus ~30% for traditional) of which 90% is recycled
- Low embodied carbon

Characteristics of modular DfMA solutions

Speed

- Extremely rapid installation on site
- Can be pre-commissioned to reduce handover period
- Requires long lead-in for factory production

Delivery

- Requires significantly fewer operatives on site
- Can significantly reduce the level of skill required on site
- Can employ low-skilled operatives to manufacture the units if design is sufficiently complete

Carbon

- Often over-engineered (for example, to be stiff enough for transport and lifting requires more structure than is required in their permanent location)
- Logistically challenging – effectively 'empty boxes' and thus less efficient in transportation terms than smaller components, which can be more densely packed
- Significant reductions in waste

Cost

- Can be more expensive than traditional solutions
- Additional cost must be countered by creating gains in speed, reduction in waste etc

Heathrow and Gatwick Pier Segregation

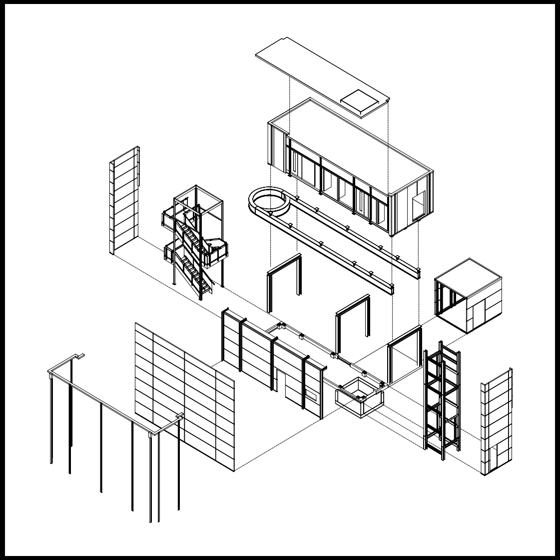
- 50% reduction in overall programme
- 36% reduction in cost vs. traditional
- 80% of work taken off site

Optimum Switch Data Centres

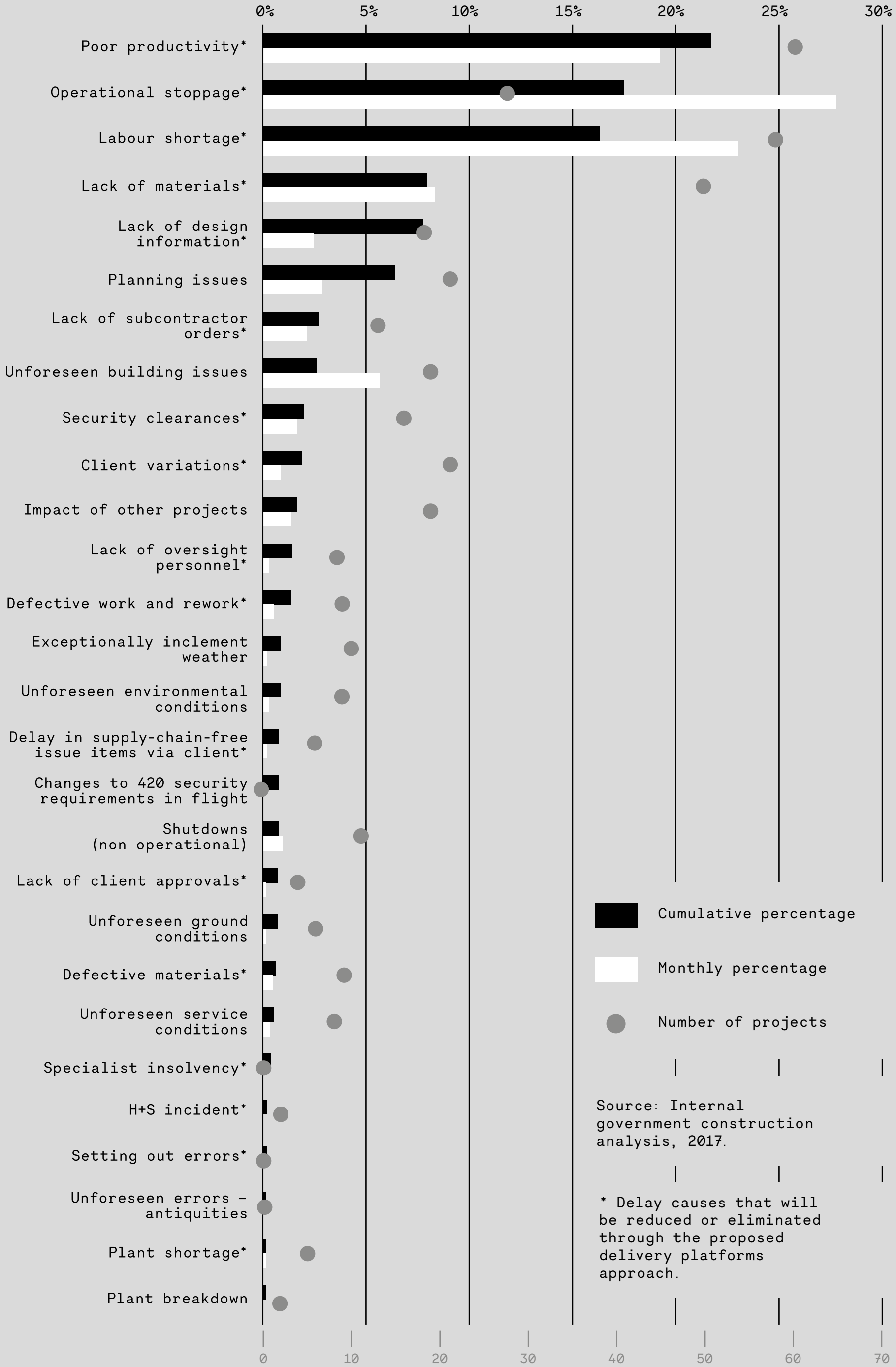
- 30% reduction in overall programme
- 40% of work taken off site
- 30% reduction in cost

Heathrow Terminal 5C Nodes

- 87% reduction in overall programme
- 65% of work taken off site
- 25% reduction in cost



Reasons for project delays



Source: Internal government construction analysis, 2017.

* Delay causes that will be reduced or eliminated through the proposed delivery platforms approach.

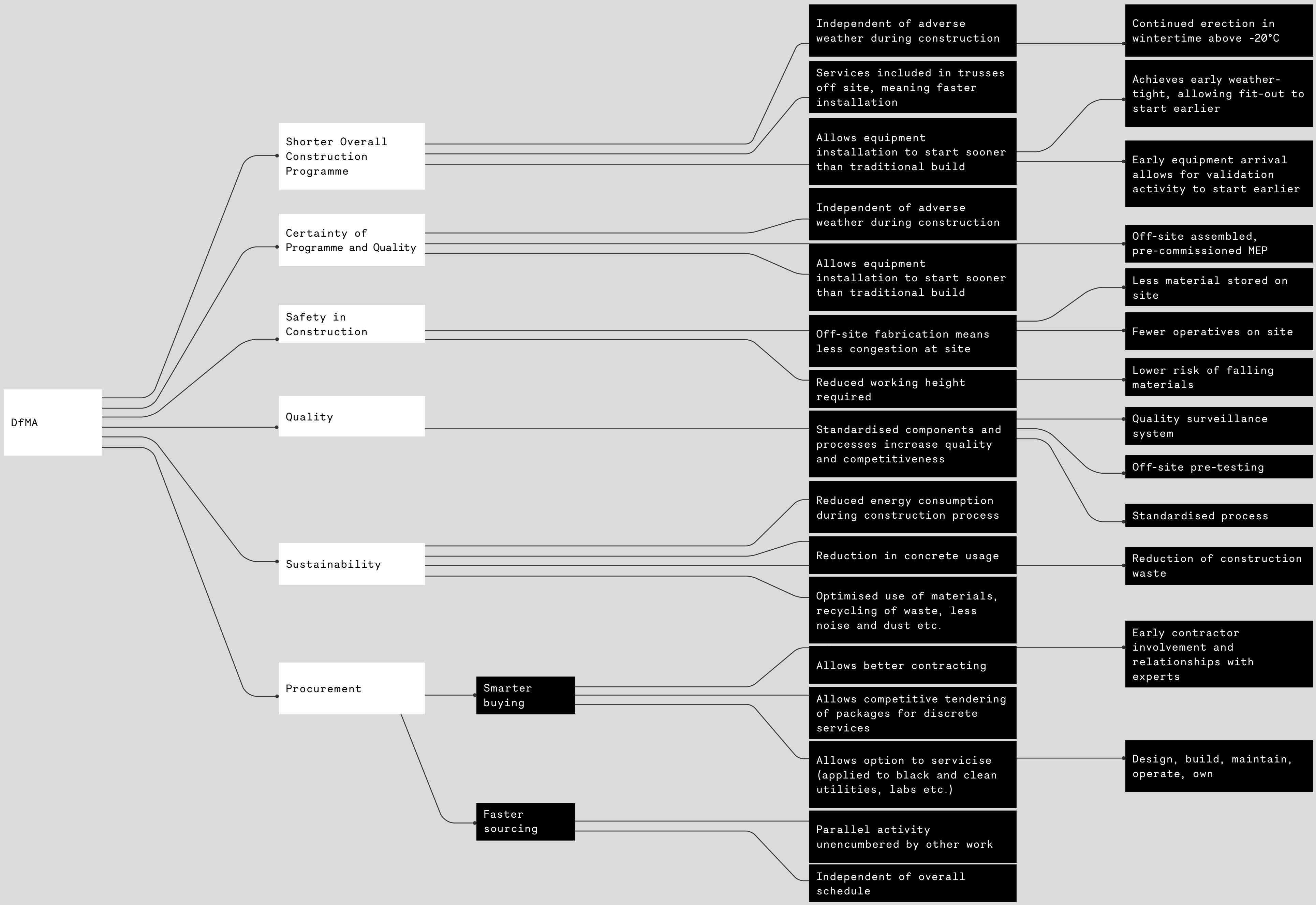
How DfMA can mitigate against challenges raised in the Government Construction Framework Analysis 2017

PPI Reason for Change	Mitigating strategy / benefits for DfMA
Poor productivity	▪ Productivity of factory staff is typically ~85% relative to ~60% for on-site workers; ▪ By utilising higher levels of factory-like conditions, overall productivity will rise; ▪ Site-based operatives will be engaged in ‘assembly’ rather than ‘construction’ tasks, creating factory-like conditions on site.
Operational stoppage	▪ Implementation of DfMA strategies allows more precise planning and execution of tasks; ▪ Taking items off critical path reduces site time; ▪ Fewer deliveries, trades and activities to plan increases certainty in the programme; ▪ Installation and assembly (as opposed to construction) sequences are more capable of precise execution.
Labour shortage	▪ Staff based on site typically cost up to twice as much as factory personnel; ▪ DfMA facilitates the use of local, low-skilled but highly productive operatives.
Lack of materials	▪ Pre-manufactured elements limit the amount of bulk or raw material required on site; ▪ Where material is required, it can be managed with the same logistical accuracy as the manufactured elements i.e. pre-cut or pre-kitted in a consolidation centre and delivered with the DfMA components. This increases productivity on site and reduces waste material.
Lack of design information	▪ Manufactured elements arrive at site having been pre-tested and quality controlled, and require no additional design information; ▪ Interfaces and installation techniques can be simplified to use snap-fit or plug-and-play connections; ▪ Installation techniques and health and safety advice can be standardised and documented for point-of-work posters and toolbox talks for consistency; ▪ Visual method statements and standard operating procedures can be linked to QR codes or RFID tags on specific components so they are always delivered with the appropriate information and documentation.

PPI Reason for Change	Mitigating strategy / benefits for DfMA
Lack of subcontractor orders	▪ Programme-wide data analysis and visualisation facilitates supply-chain engagement, factory planning and smoothing of demand; ▪ Simplified design of components and the ability to deliver these using a wide and resilient supply chain reduces stress on individual suppliers.
Security clearances	▪ Fewer operatives on site reduces the need for time and management related to security clearances; ▪ Quality-assurance processes at the point of manufacture can include security checks; ▪ Reduced programme and on-site personnel means reduced management and site preliminaries.
Lack of escorts	▪ Fewer operatives on site reduces the need for time and management related to escorts.
Defective work and rework	▪ Applying quality-assurance processes and procedures to the manufacture, testing and pre-commissioning of DfMA elements will dramatically reduce instances of defective elements reaching site; ▪ This can result in an improvement of up to 70% in reworking and snagging; ▪ Limiting works on site inherently reduces the amount of damage by following trades; ▪ Use of pre-kitted parts and standard operating procedures at the point of work significantly reduces reliance on trades and workmanship; ▪ Research data suggests DfMA reduces site waste by 70 to 90%.
Delay in free issue items via client	▪ As 'lack of subcontractor orders' above.
Lack of client approvals	▪ As 'client variations' above.
Defective materials	▪ DfMA components allow waste reduction through better stock control.

PPI Reason for Change	Mitigating strategy / benefits for DfMA
Specialist insolvency	▪ As 'defective work and rework' above.
Health and safety incident	▪ By limiting the number of hours on site, adverse consequences are reduced resulting in an 80% reduction in incidents; ▪ DfMA can significantly reduce the need for work at height (falls are the leading cause of serious injuries, accounting for 48% of health and safety incidents on construction sites); ▪ Reduced traffic movements to and from sites leads to improved neighbourhood road safety – up to 20% reduction in road accident data within 0.5km of site.
Setting out errors	▪ DfMA elements arrive quality assured for dimensional accuracy and tolerance; ▪ Simplified interfaces reduce reliance on workmanship for accuracy; ▪ Connections can be made to automatically align with other components, or include some form of final adjustment.
Plant shortage	▪ Accuracy (e.g. regarding the duration of specific tasks) will be achieved through virtual and physical prototyping to improve logistics planning; ▪ Programme-wide data analysis of planned and actual tasks will allow responsive logistics models and agile planning tools; ▪ Use of standard operating procedures and lower numbers of personnel on site will reduce instances of unplanned activity.

Benefit Areas of DfMA



A Platforms Approach to Design for Manufacture and Assembly

A traditional project-level approach

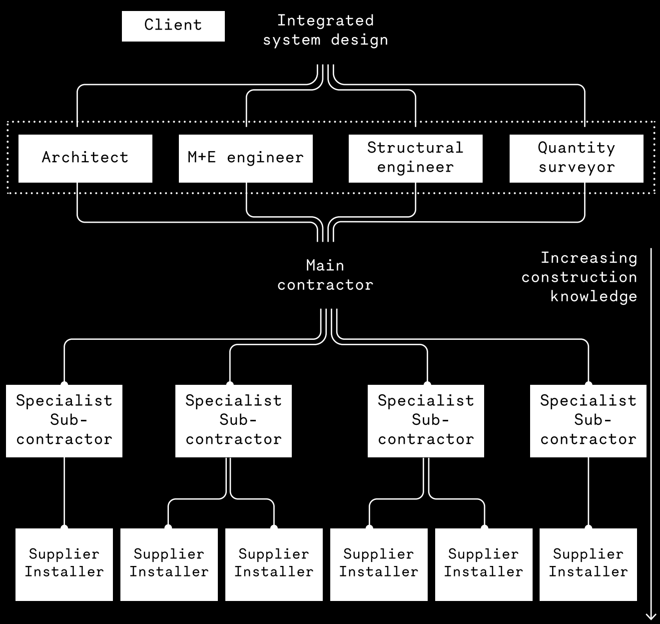
In a traditional one-off project, each asset is modelled, and information for design, tender and construction is created individually. The design team can only afford to describe the proposed solution to a certain level of detail, which is then developed by the contractor in conjunction with their supply chain. Typically the degree of repetition at project level is low and only warrants highly detailed analysis of a few key areas.

The fact that the design development (project knowledge) often takes place in isolation from the supply chain is a significant source of missed opportunities to optimise the design and leverage best-in-class construction knowledge.

In addition, most of the construction knowledge sits within the supply chain which may be fragmented and have little opportunity for collaboration. This is a significant source of rework and duplication of effort.

As a result, any benefits that are generated by innovation generally remain within the supply chain and are not passed on to the client for wider use. Any knowledge that is gained through the project cannot typically be captured, disseminated and improved to the benefit of other projects.

Traditional procurement model



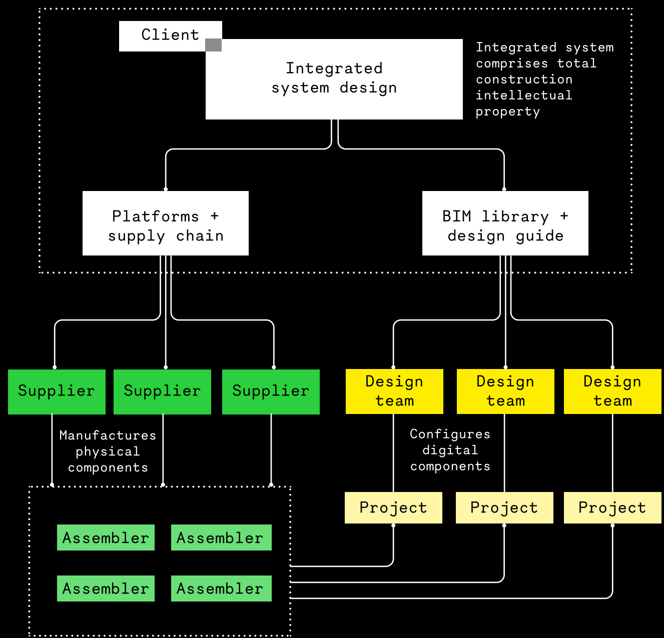
A programme/ portfolio approach

A platforms approach to DfMA will elevate DfMA beyond single-project benefits.

By increasing scale, moving from projects to programmes, working both cross department and cross sector, platforms can achieve the economies of scale and consistency of pipeline that unlock the benefits of manufacturing as yet unrealised.

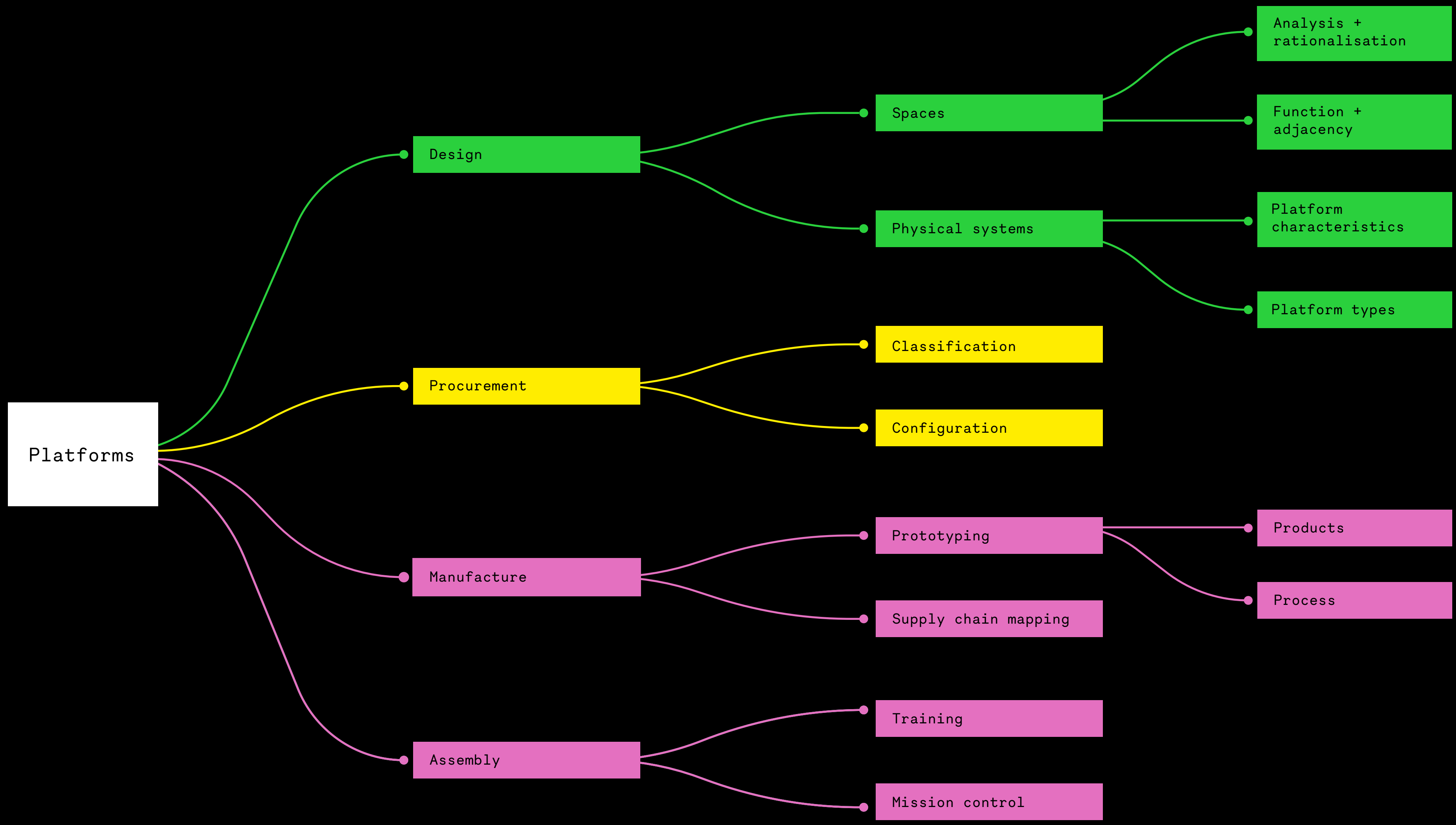
Developing components for large-scale deployment, where knowledge is captured and retained for further collaborative refinement, would facilitate continual improvement (as is common in the automotive and aerospace industries) as opposed to constant reinvention (as is common in traditional construction).

Potential procurement route for an integrated programme approach



By increasing scale, platforms can achieve the economies of scale and consistency of pipeline that unlock the benefits of manufacturing

The components of a platform approach



Design

Spaces

Space

To design platforms for construction, it is necessary to be able to describe projects at a range of levels of scale, from entire facilities down to individual components and products. It is also crucial to be able to move between levels of detail, from very high-level descriptions of facilities to highly comprehensive information.

It is critical that we start to think in terms of spaces – not sectors, not buildings.

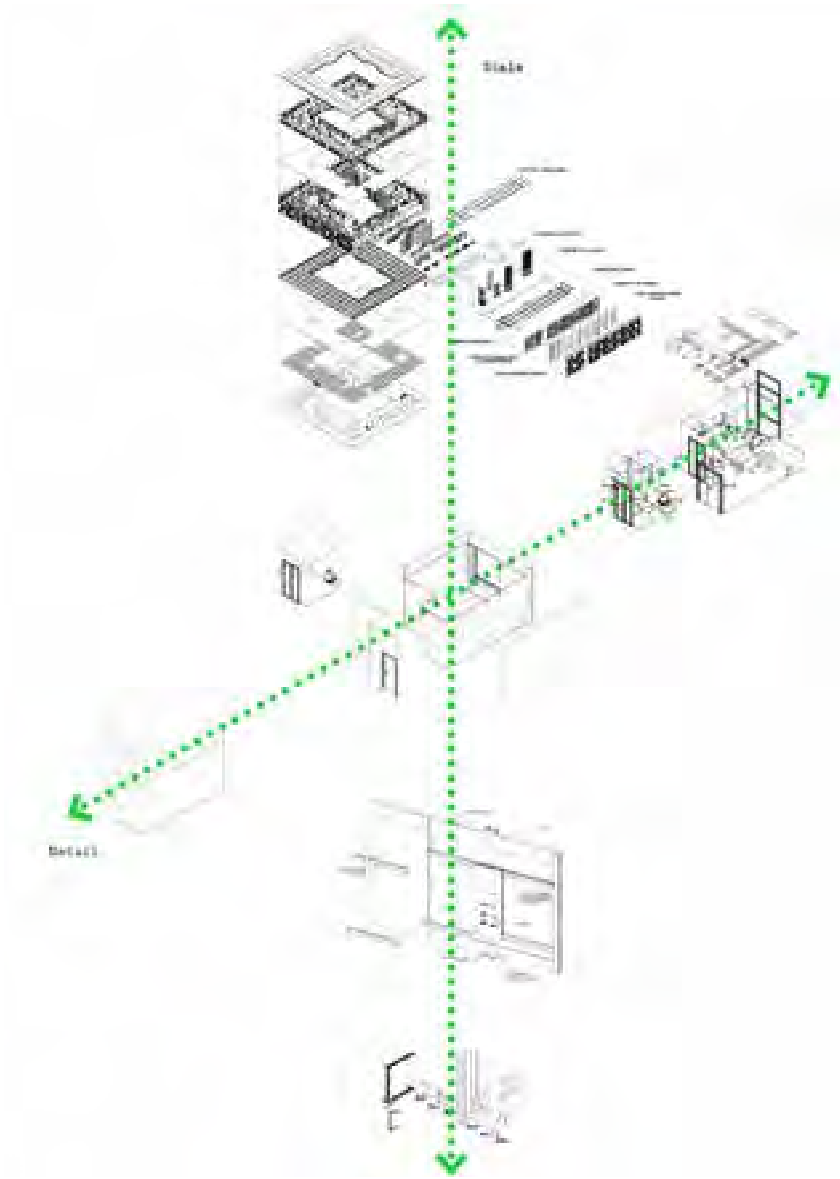
Spaces form a useful 'origin', since the majority of human activity takes place within a physical space and it is generally very easy for people to conceptualise and visualise at this scale.

Building functions are also typically described by the spaces they contain, so spaces are also a useful way of engaging stakeholders.

The activities and processes that take place within a facility are governed by the characteristics of their spaces in terms of the following:

- Dimensions (clear span, clear height)
- Number of storeys (how many spaces can be reasonably stacked)
- Density and type of structural load that can be applied (dictating amount of storage, equipment etc. that can be placed in a space)
- Availability or density of mechanical and electrical services such as heating, cooling, lighting, power etc.
- Specialised requirements for processes or equipment relating to the specific asset use
- Specialised functional needs (e.g. in terms of security)

Assets redefined as 'spaces'



Analysis and rationalisation

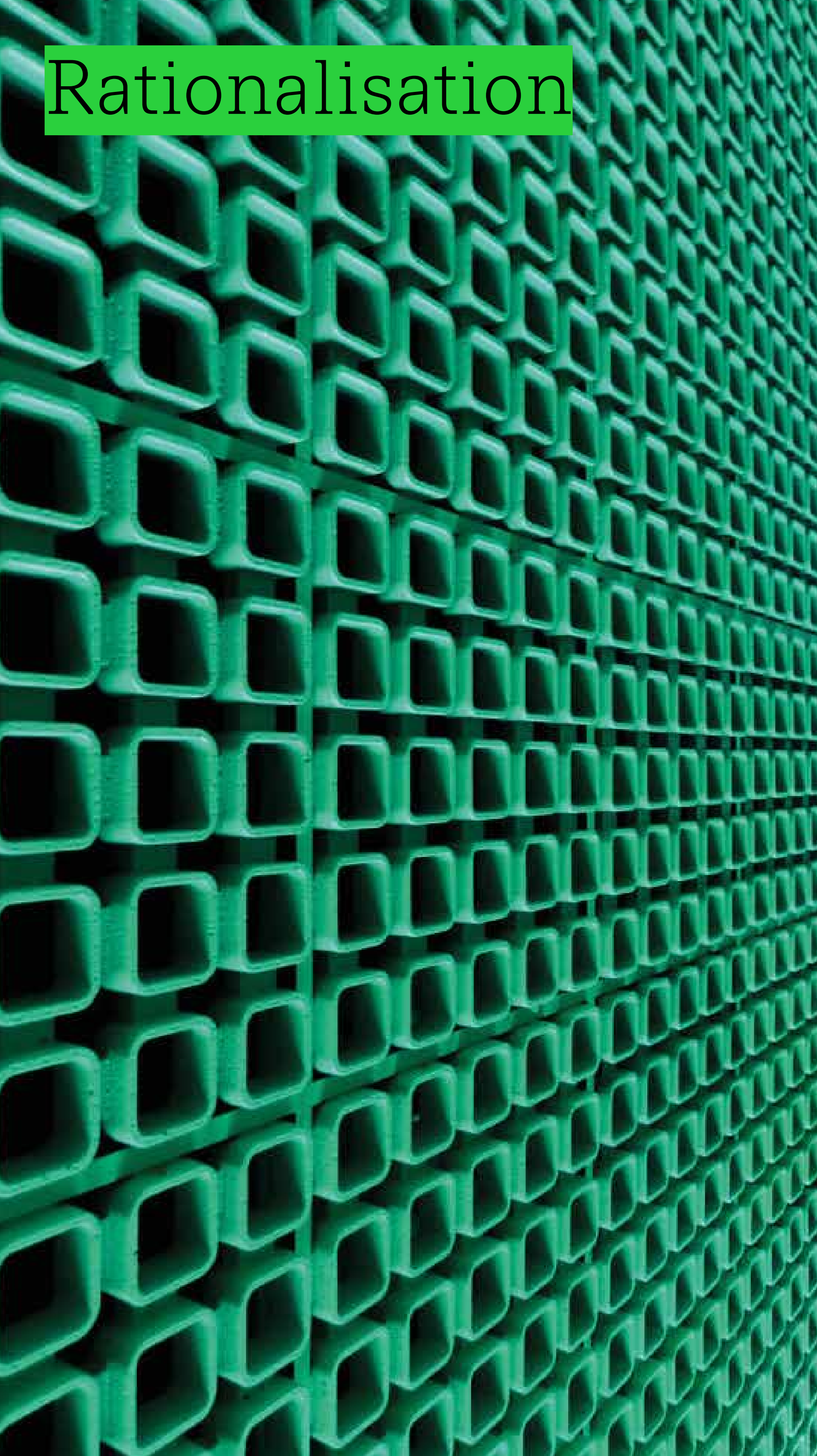
One of the government's strategic aims is to leverage benefits across government spend by using standard, repeatable processes and designs. Therefore a key part of platform strategy will be to establish where standardisation adds the most value i.e. where the time and effort in optimising something is justified by its overall value to the delivery of multiple assets.

It is anticipated that a relatively small number of repeatable elements (at a range of scales from components to entire assets) could deliver a significant proportion of government need. Optimising these repeatable solutions therefore has enormous benefits.

The size of the repeatable elements (the degree of granularity) will vary according to the size and nature of their function, degree of complexity and frequency across likely asset types.

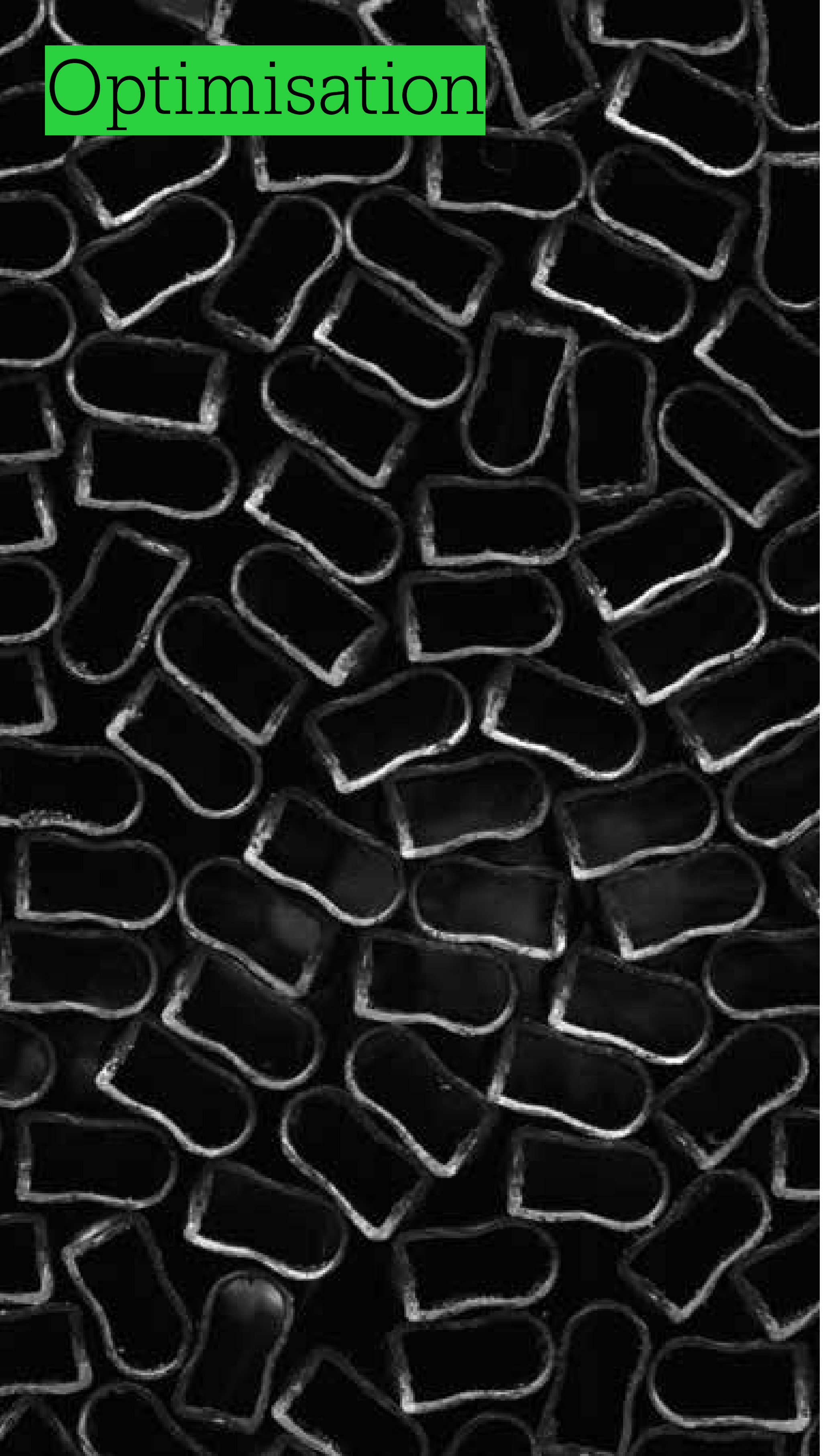
For some elements, site-wide standardisation at the level of the building may be beneficial; in other cases standardisation at the level of a room type might be more appropriate, and this approach will continue down to typical connections or interfaces.

In order to identify where standardisation should be applied to add value without compromising functionality, solutions will be interrogated and refined through a process of:


Rationalisation


Standardisation

Optimisation



Rationalisation

By reviewing previous and proposed solutions, a range of analytical tools will be applied to group similar elements. These can then can be tested to ascertain whether the degree of variation within the group (i.e. the range of different solutions to the same problem or brief) is necessary or whether a common solution could be adopted.

Standardisation

The rationalisation process will yield a number of common solutions with a high rate of occurrence. These will provide significant benefits in terms of speed of design, ease of construction, opportunities for standard working etc.

These standard elements can then be refined with stakeholders and, where appropriate, the likely supply chain to develop consistent and reliable layouts, interfaces, details and materials specification to ensure regulatory conformity, long life and minimum defects.

Optimisation

Further benefits may be realised by continuing to refine certain components – highly repeatable elements that will justify significant time and effort in refining the design. The cost of the product can further be reduced by optimising the use of materials (specification, thickness etc.) to meet the requirements for robustness and durability without being overspecified.

This approach is particularly beneficial where it facilitates programme-wide procurement with associated benefits of mass production and manufacture at an industrial scale.

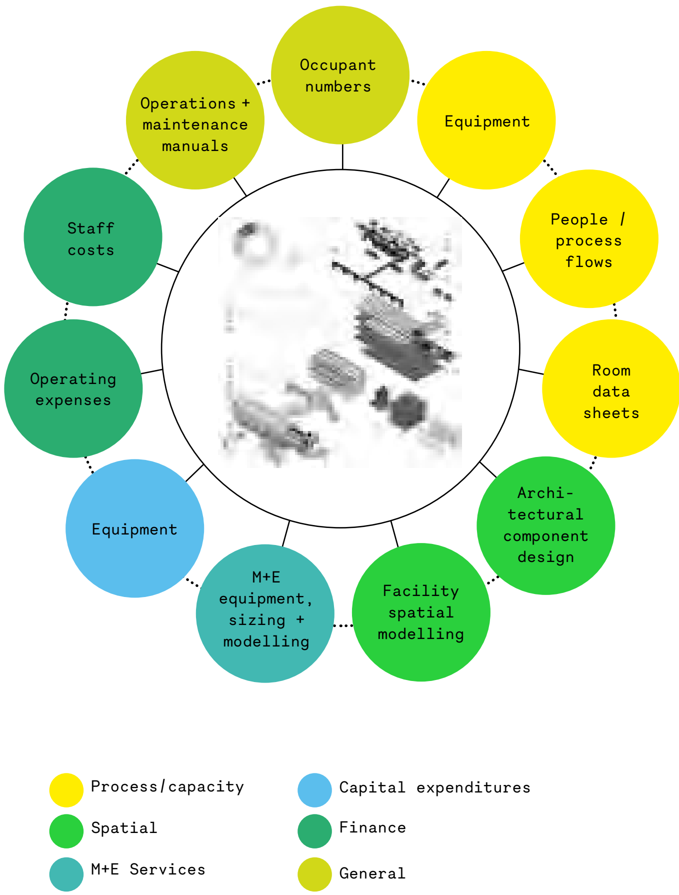
Stakeholder perspectives

The initial need for spaces, and their functional requirements, can generally be identified through schedules of accommodation and technical standards generated on previous projects.

The initial spatial needs can be interrogated, refined and more precisely articulated through a variety of stakeholder perspectives to describe every aspect of how a space needs to function, as well as the people, processes and activities it needs to accommodate, etc.

The room properties (from, for instance, standard room data sheets) can then be captured and enriched (if required) with input from key stakeholders representing a number of operational and functional specialisms.

Traditional procurement model



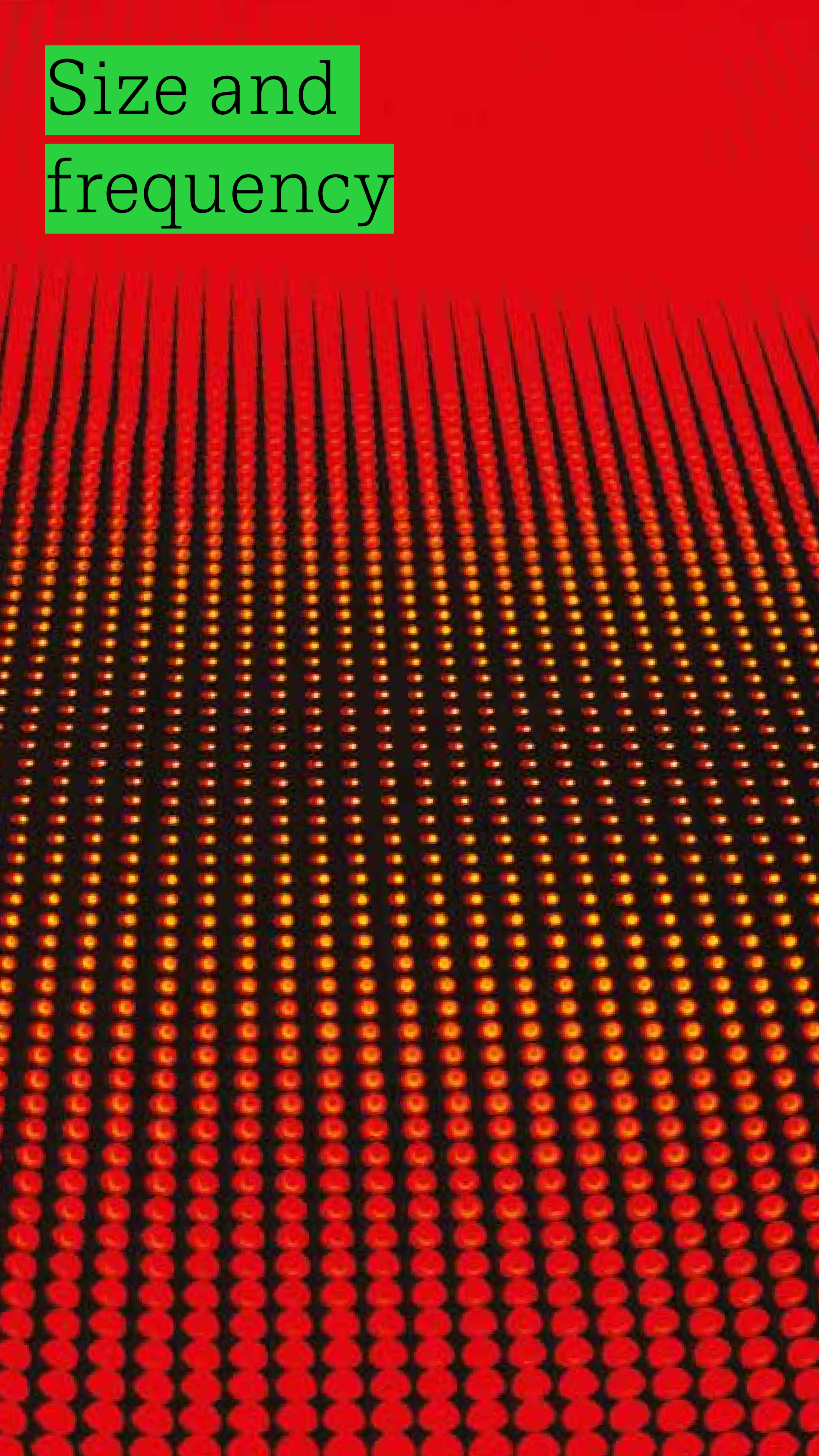
A sensible starting point of the standardisation process would be to analyse the spaces delivered over a range of previous, representative projects within a sector.

This analysis will look for patterns in

- Distribution of the different room areas and typologies in order to develop a reduced number of common room sizes, but with an increase in the frequency of each;
- Analysis of the most highly repeated and complex (i.e. high value) room types where the benefits of an industrialised approach will have the most impact.

Using schedules of accommodation to identify unique room types – their areas, frequency of occurrence and in which buildings they occur – would facilitate an analytical approach to understanding the degrees of commonality and variation between different space types in terms of:

Size and frequency



Complexity

Size and frequency

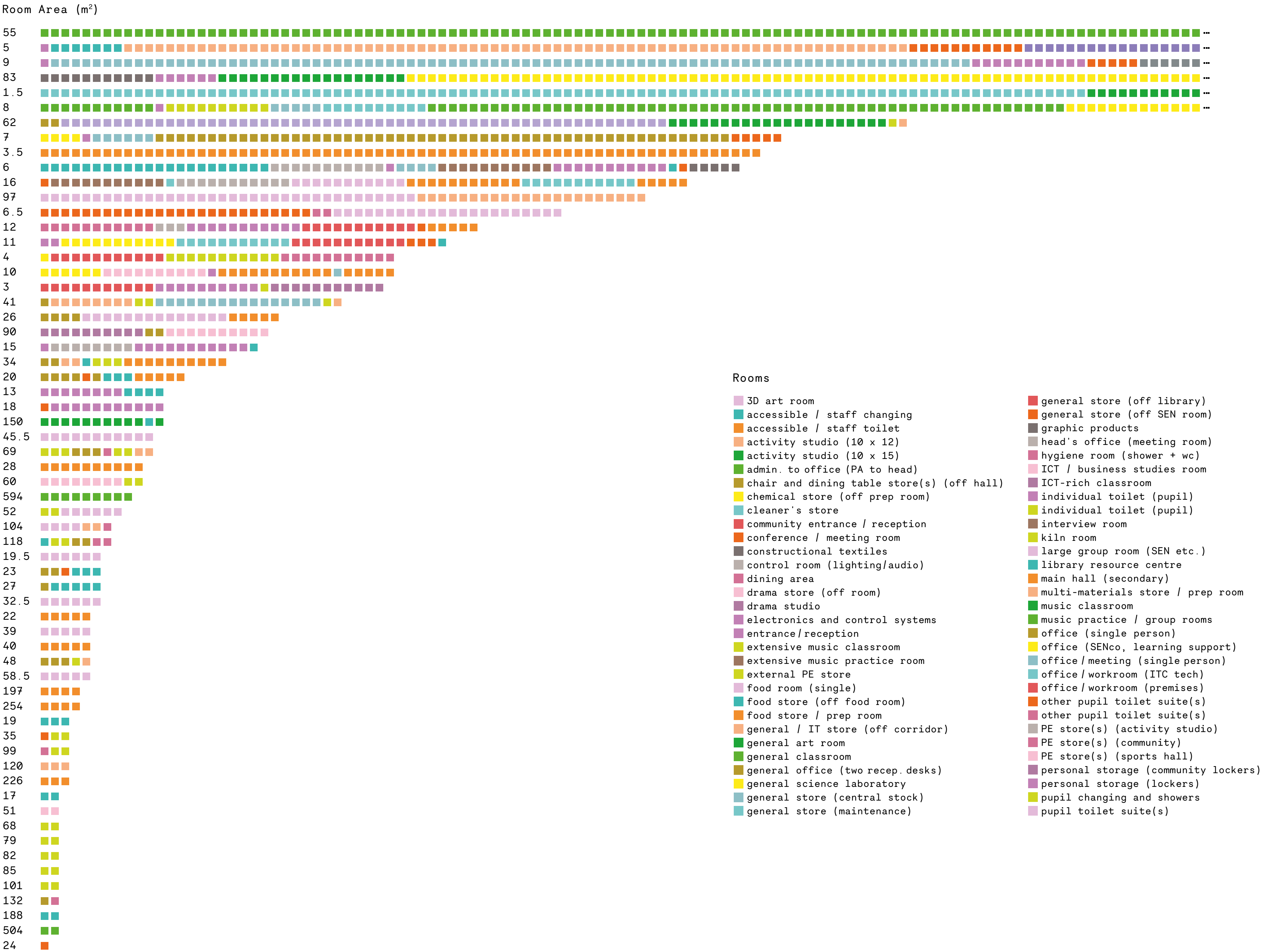
The design of high-frequency rooms should be standardised as much as possible in order to increase repeatability.

Where there are rooms of a similar size which occur with low frequency, there could be an opportunity to rationalise these rooms to a common area. This would result in certain rooms becoming larger whilst others become smaller. It must be ensured that these rationalised rooms remain functional with their revised areas.

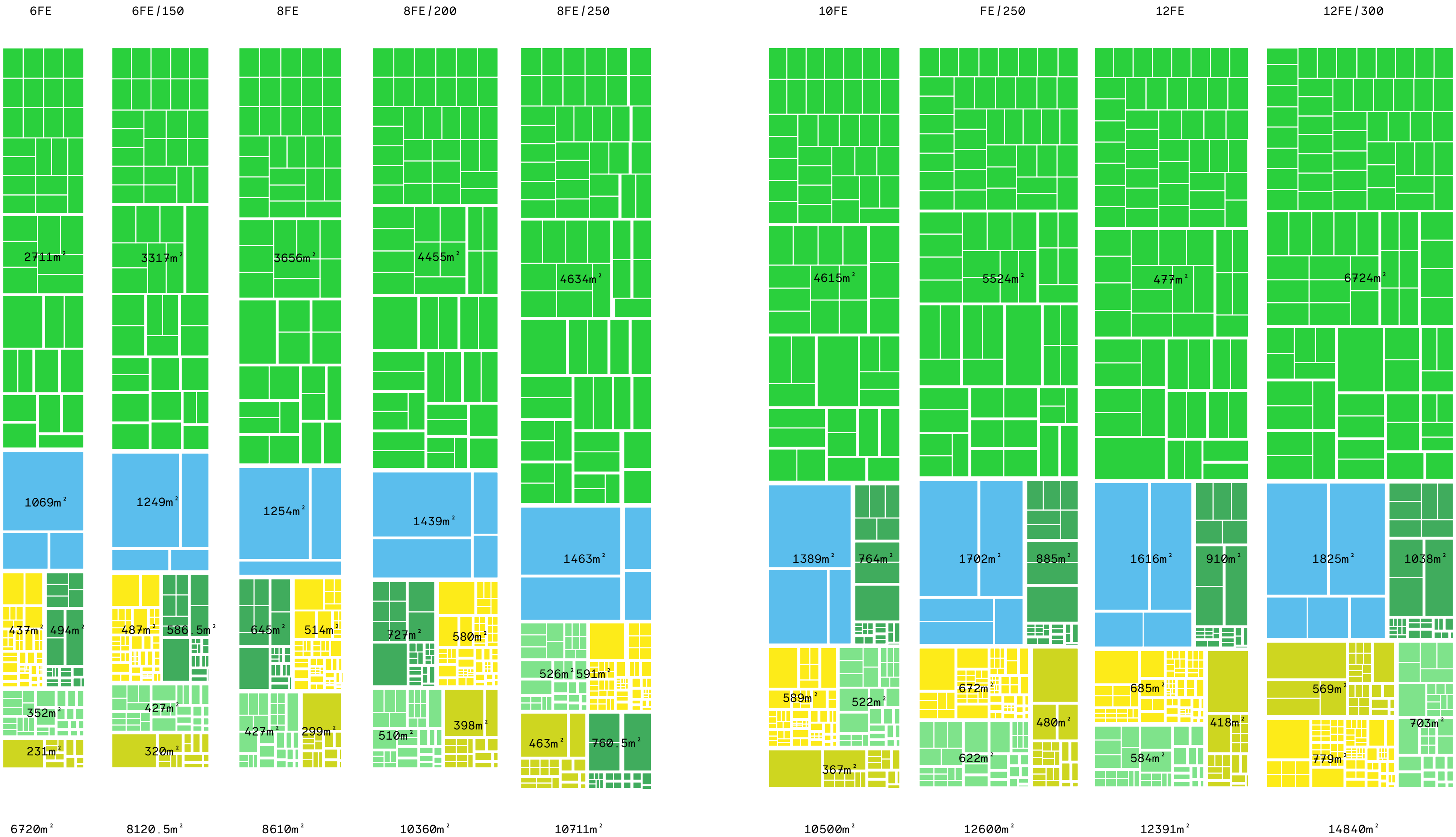
It will therefore be possible to rationalise the number of space types into a smaller (and therefore more manageable) number of types with common properties, a higher degree of standardisation in the fit-out and operational stages, and also offer the ability to repurpose spaces of one type to another type with similar properties

In this way, it should be possible to allow for the over-provisioning of space (i.e. providing generous room sizes) or mechanical, electrical and plumbing (providing future proofing and flexibility) at zero or reduced cost by achieving higher levels of standardisation and therefore leveraging the benefits of industrialisation.

Size and frequency of spaces across the Education and Skills Funding Agency



Size and frequency of spaces across the Education and Skills Funding Agency



- Basic teaching spaces
- Large spaces
- Learning resources areas
- Staff and administration areas
- Storage
- Non-net areas

This visualisation indicates the overall Gross Internal Floor Area (GIFA) of each school within the sample, determined by the schedule of accommodation. Every room is represented by a single rectangle, which is sized proportional to its area and coloured by department. A standard packing approach has been adopted, which groups rooms by department in order to indicate the relative size of the departments within the school. It is not representative of adjacencies. It can be concluded that the initial focus should be developing a standardised approach for the teaching spaces, as these represent a significant proportion of the school accommodation overall.

Complexity

Factors that will be used to judge the relative complexity of space types will include the requirement for the provision (and density) of mechanical and electrical services.

By aggregating the mechanical, electrical and plumbing (MEP) requirements from the rationalised space types, it will be possible to generate high-level requirements for mechanical and electrical plant, including schedules for:

- Estimate of total anticipated building generator load (kVA)
- Estimate of total HVAC loadings (m^3/s)
- Estimate of total cooling plant loading (KW)
- List of recommended electrical rooms and sizes based on adjacency diagrams
- List of recommended IT / data rooms and sizes based on adjacency diagrams

This will facilitate the testing of high-level strategies, primary system selection etc., as well as providing a benchmark for testing design development and potential opportunities.

Analysis of complexity across the Education and Skills Funding Agency

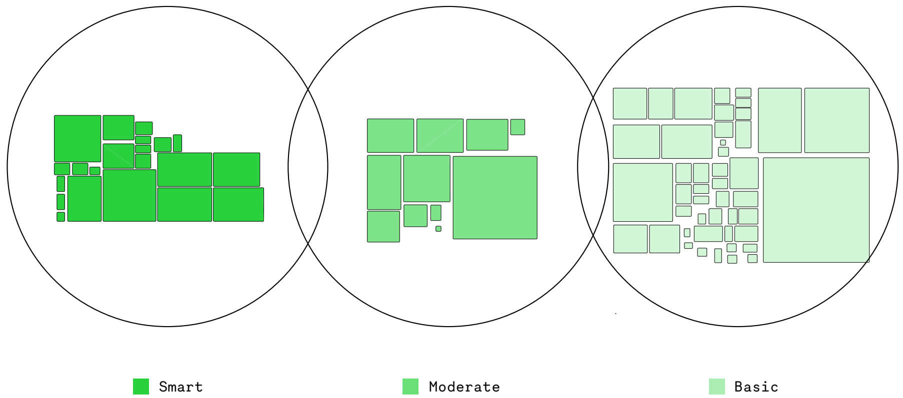
Room intelligence

High → Low

Serviced rooms such as corridors, bathrooms, kitchens, plant and servers.

Partially serviced rooms containing some fittings or sinks.

Unserviced rooms with limited fittings.



Mechanical Properties

AHU Number
Boiler Power
Cold Water Requirements
Drainage List Quantity
Drainage Requirements
Extract ACH
Extract Airflow Rate
Heating/Cooling System Type
Hot Water Requirements
Number of Domestic Hot and Cold Water Connections
Primary Cooling Load
Primary Heating Load
Primary Heating/Cooling Type
RO Water Requirements
Sanitary Waste
Secondary Cooling Load
Secondary Heating Load
Secondary Heating/Cooling Type
Softened Water Requirements
Special Waste
Supply ACH
Supply Airflow Rate

Electrical Properties

Electrical System Clinic Category
Equipment Load
Fire Alarm
Lighting Illuminance
Lighting Lamp Source
Lighting Working Plane
Number and Type of Electrical/Data Outlets per Room
Nurse Call
Power Total Space
True Power

Specialist Requirements

These would vary by sector and project. However, in a healthcare context, these would include medical gases e.g.:
Oxygen
Medical Air
Surgical Air
Oxygen / Nitrous Oxide Mix
Nitrous Oxide
Carbon Dioxide
Helium/Oxygen Mix
Nitrogen
Medical Vacuum
Anaesthetic Gas Scavenging

Function and adjacency

Once the spaces have been identified and rationalised, they can be arranged into idealised adjacencies and flows.

Once all senior stakeholders have identified exactly what the functional organisation is that is required to meet their needs, a diagram can be developed using the information about spatial requirements that is contained within the library of space types.

This would allow the creation of a detailed whole-facility spatial diagram that can be reviewed and validated by all relevant stakeholders.

This diagram is then loaded with all the detailed general and technical requirements for each, which becomes the brief for the building and building-system design.

A number of these diagrams already exist for flows in courts and prisons and could be expanded to include healthcare, schools etc.

Benefits include

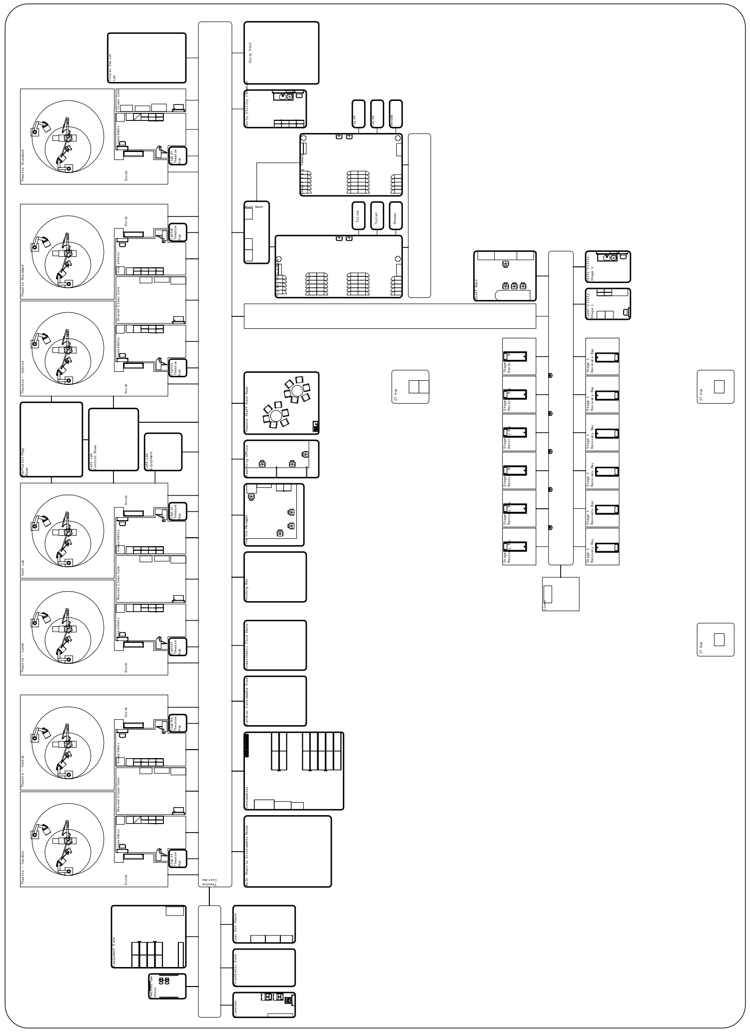
- A very user-friendly interface with an early-stage Building Information Model (BIM), ready for the application of subsequent layers of data (e.g. cost, room data sheets etc.);
- Actual requirements able to be interrogated and understood (rather than assumed or discussed based on geometric/physical constraints);
- Highly targeted stakeholder engagement, feedback and approval;
- Diagrams can be filtered to show a number of different critical requirements for specific stakeholders e.g.:
  - user (pupil, patient etc.), staff, visitor, operational flows
  - security and access
  - facilities management;
- Schedules of accommodation (SoA) generated directly from the diagrams.

Healthcare facility: Library of spaces

High Level Functionality	Functionality						
Surgery Care requiring surgical intervention	Cardiac						● 30 bed
	Vascular					● 30 bed	● 30 bed
	Cardiac Arrhythmia					● 30 bed	● 20 bed
	Thoracic					● 30 bed	● 20 bed
	Coloproctological					● 30 bed	● 20 bed
	Oncology						● 30 bed
	Abdominal I					● 30 bed	● 30 bed
	Abdominal I I						● 30 bed
	Plastic/Reconstructive						● 10 bed
	Trauma					● 30 bed	● 30 bed
	Orthopedic					● 30 bed	● 30 bed
	Neurosurgery					● 2x60 bed	● 30 bed
	Gynaecology					● 30 bed	● 30 bed
	Otorhinolaryngology					● 30 bed	● 30 bed
	Orthognathic						● 20 bed
	Urology					● 30 bed	● 30 bed
	Endourology/Laparoscopy						● 30 bed
	Ophtalmology						● 30 bed
	Purulent Surgery					● 30 bed	
	Burns Unit					● 30 + 5ch	
	Microsurgery					● 30 bed	
	Transplantology & Endocrine					● 30 bed	
	Concomitant Injury					● 30 bed	
	Oromaxillofacial Surgery					● 30 bed	
	Operating Theatres	General Operating theatre	● 5 theatres		● 2	● E4+28	● E4+10
		Specialised theatre	● 2 theatres				
		X-ray theatre (with Angiography)	● 1 theatre				● 2
		Diagnostic and Cardiac theatre					● 1
		Vinci Surgical System theatre					● 4
		Surgical Microscope theatre					● 3
	First Stage Recovery		●		● 4		●
	Transfusion						●
Critical Care Care of critically ill patients	Emergency		● 50 bed				
	General			● 6 bed	● 4 bed	● 18 bed	● 12 bed
	Cardiac						● 36 bed
	Neurological					● 18 bed	● 12 bed
	Pulmonary, Dermatological etc.						● 12 bed
	Heart disease						● 18 bed
	Hematology, Transplantation						● 18 bed
	Burning Injury					● 12 bed	● 9 bed
	Purulent Surgery					● 12 bed	
	Selected Surgery					● 12 bed	
	Trauma					● 12 bed	
Rehabilitation Restoring personal autonomy of patients	Rehabilitation					● 200 pl	● 320 bed
Cancer Care Diagnosis and treatment of cancer	Cancer Daycare				● 20 bed		●
	Cancer Therapy				● 40 bed		● 30 bed
	Procedure				● 4		●
	Chemotherapy				● 2		●
Renal Care Treatment of patients w/ renal conditions	Dialysis						● 40 bed
Transplantation Transplanting organs and care of patients	Transplantation						● 10 bed
Primary & Community Care Delivering primary & community care to patients	Primary & Community Care						
Maternity Care Care for women when pregnant or during childbirth	Maternity Care						
Pediatric Care Care for children	Pediatric Care						
Mental Health Treatment & accommodation for mentally ill patients	Mental Health						
Older People Providing care for older people	Older People						
Dentistry	Dentistry					●	
Outreach	Outreach						
Educational & Research Educating medical personel & doing clinical research	Education	Student Education					● 6000s 3000d
		Cont Postgraduate Training					● 32000d
		Experimental Train/Research					●
		Experimental Biology					●
Support Functionality Providing support services to core functionality	Pharmacy		●				●
	Pathology		●	●	●	●	●
	Decontamination		●	●	●	●	●
	Medical Inspection						
	Waste handling		●	●	●	●	●
	Nutrition		●	●		●	●
	Laundry		●	●	●	●	●
	Facilities Management		●	●	●	●	●
	General Administration		●	●	●	●	●
	General Purpose			●		●	
	Staff Accommodation					● 692p	

Spatial adjacency diagram for operating theatre suite

Surgery Care requiring surgical intervention	Oromaxillofacial Surgery					● 30 bed	
	Operating Theatres	General Operating theatre	● 5 theatres		● 2	● E4+28	● E4+10
		Specialised theatre	● 2 theatres				
		X-ray theatre (with Angiography)	● 1 theatre				● 2
		Diagnostic and Cardiac theatre					● 1
		Vinci Surgical System theatre					● 4
		Surgical Microscope theatre					● 3
	First Stage Recovery		●		● 4		●
	Transfusion						



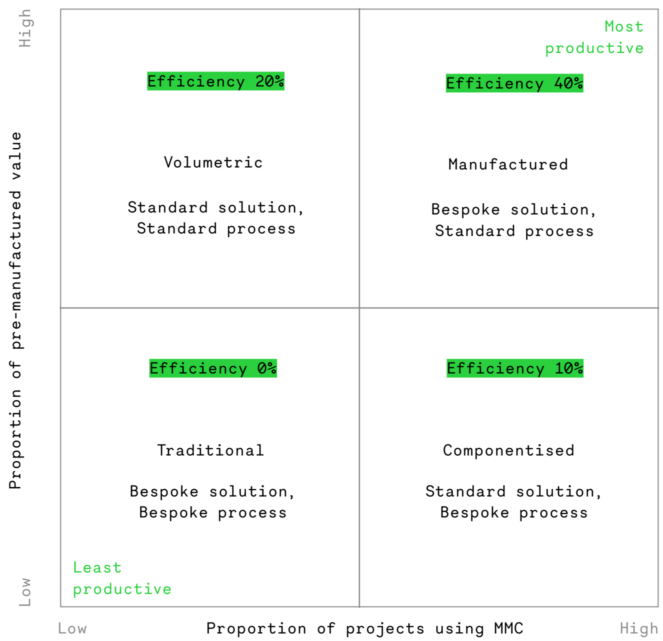
Physical Systems

Platform characteristics

The adoption of a platform approach requires standardisation of both the product and process.

The following axes help us to define what constitutes a successful platform, mapping initiatives from least to most productive.

Mapping modern methods of construction (MMC) initiatives from least to most efficient



Volumetric solutions are standardised in terms of design, manufacture and delivery and as a result may be significantly more efficient than traditional. However, the level of customisation tends to be very low; setting up even a relatively unsophisticated manufacturing facility requires significant investment, which is amortised through the delivery of units and dictates as much standardisation as possible. An automotive example would be the Ford Model T, which dramatically lowered the cost of a car but was famously available in 'any colour, as long as it is black.' To increase customisation requires more sophisticated tools, with higher investment, and greater unit numbers to amortise the cost.

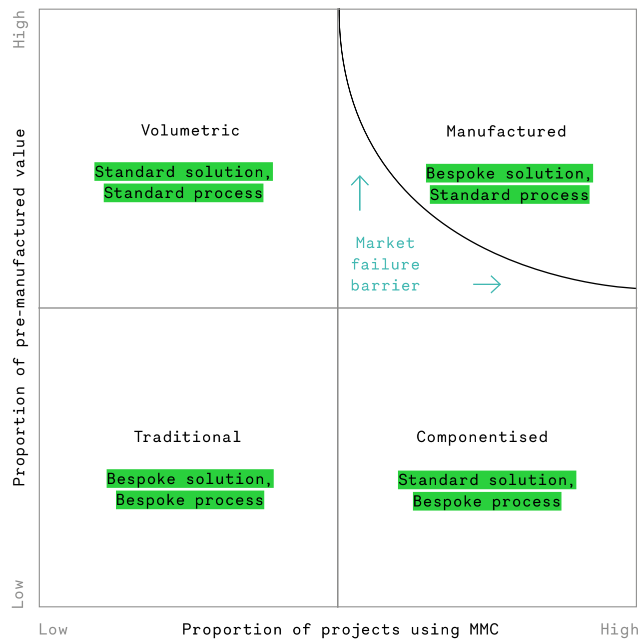
Traditional construction is characterised by bespoke solutions, being delivered by a bespoke process. The adoption of MMC and creation of value off site is low. As a result efficiency is low, making this the least productive (but most common) form of construction.

Manufactured solutions use standardised processes to deliver bespoke solutions. Continuing the automotive analogy, this would be comparable to today's highly sophisticated 'build to order' manufacturing plants and models such as Ford Transit, which have an estimated thirteen million combinations.

Componentised delivery uses standard solutions, but the way they are deployed is not controlled. An example would be a project that uses standard room data sheets, BIM library objects or sub-assemblies, but delivered within the context of a largely traditional one-off project; the efficiency in adopting the standardised components has little impact on the project overall.

Additionally, to reap the benefits of manufactured solutions, all elements within the supply chain need to be standardised, working to the same rules, procedures and techniques.

The 'market failure' barrier



There is a 'market failure' barrier to achieving truly manufactured solutions, the reasons for which cannot be overcome by any single programme of works. Only by coordinating government investment into a limited number of consistent platforms can enough critical mass be achieved to develop the solutions that are needed to push beyond the barrier.

In the 1980s and 1990s, the 'Big Three' US car manufacturers (Ford, General Motors and Chrysler) were forced to collaborate in creating a level of industry standardisation in order to counter the threat posed by Japanese competition. Toyota had successfully implemented Total Quality Management which allowed them to significantly penetrate US markets due to better quality products, shorter cycle times and lower costs. As a result, the automotive industry (and later aerospace) introduced industry quality standards including Advanced Product Quality Planning (APQP) and Production Part Approval Process (PPAP) to their supply chains. This is described in more detail in the MTC's document *Advanced Product Quality Planning: A Quality Oriented Approach to Planning* (see p. 240).

Today, the construction industry faces a similar threat from China, Germany and Sweden, who have successfully adopted manufacturing methods, focussing on both standardisation and quality to produce highly competitive volumetric and manufactured products.

The 'Design: Spaces' chapter (78–103) describes how to yield a wide range of spaces required across the government estate.

However, within this large number of types and levels of complexity, the characteristics that define spaces and indeed entire assets will, for the vast majority, sit within some well-defined ranges.

Understanding these characteristics, and the ranges within which most buildings sit, will provide some valuable insights into what type of platforms might be most useful.

It is hypothesised that a small number of platform types would be able to create the complete range of space types that would be needed by the government estate (and also the majority of private sector). Thus, it is necessary to explore what their chief characteristics would be:

1. Physical dimensions

The physical dimensions of any space will have two primary factors:

- Clear span
- Clear height

The diagram on the right shows the location of a number of common space types in a number of sectors. Note there is a large cluster towards the bottom left (relatively small spans, clear heights), with a few building types requiring significantly larger clear heights and spans.

2. Building height

The total number of storeys is another key factor, again with a limited range:

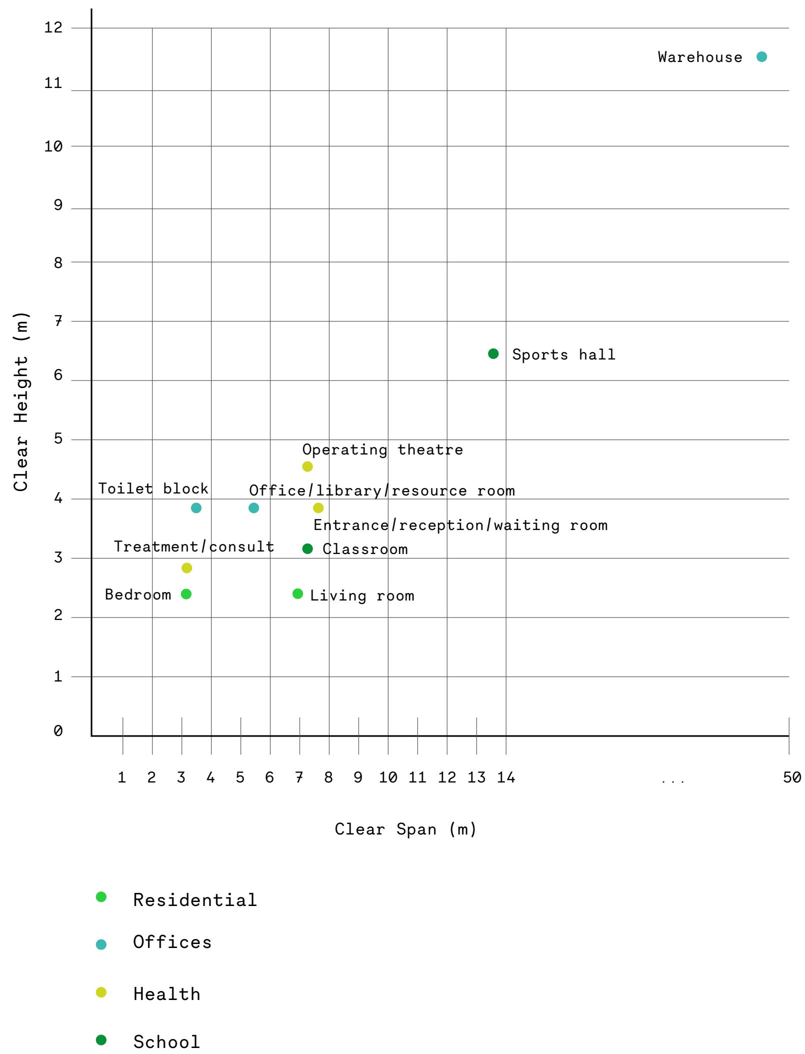
- Large-span spaces tend to be 1 to 2 storeys;
- Small-scale domestic buildings and school and prison buildings tend to be 1 to 4 storeys;
- Mid-rise office/domestic space sit within 5 to 15 storeys;
- High-rise office/domestic spaces will generally be 16 to 25 storeys.

While of course there are numerous buildings that are taller, they make up a relatively low proportion of all buildings and may not warrant a 'platform'.

3. Number of buildings

While the creation of platforms should extend beyond any single programme, the need for a high number of very similar or even identical buildings (e.g. the Education and Skills Funding Agency priority-schools programme or house blocks for the MOJ prison-estates programme) will warrant a particular focus, as the amount of repetition will have a multiplier effect in leveraging the benefits of standardisation.

Map of physical dimensions



4. Level of complexity

The space-type analysis will suggest an overall complexity of the asset type, from heavily-serviced buildings with high operational and maintenance costs to simple buildings with relatively straightforward provision in terms of heating/cooling, lighting, power distribution etc.

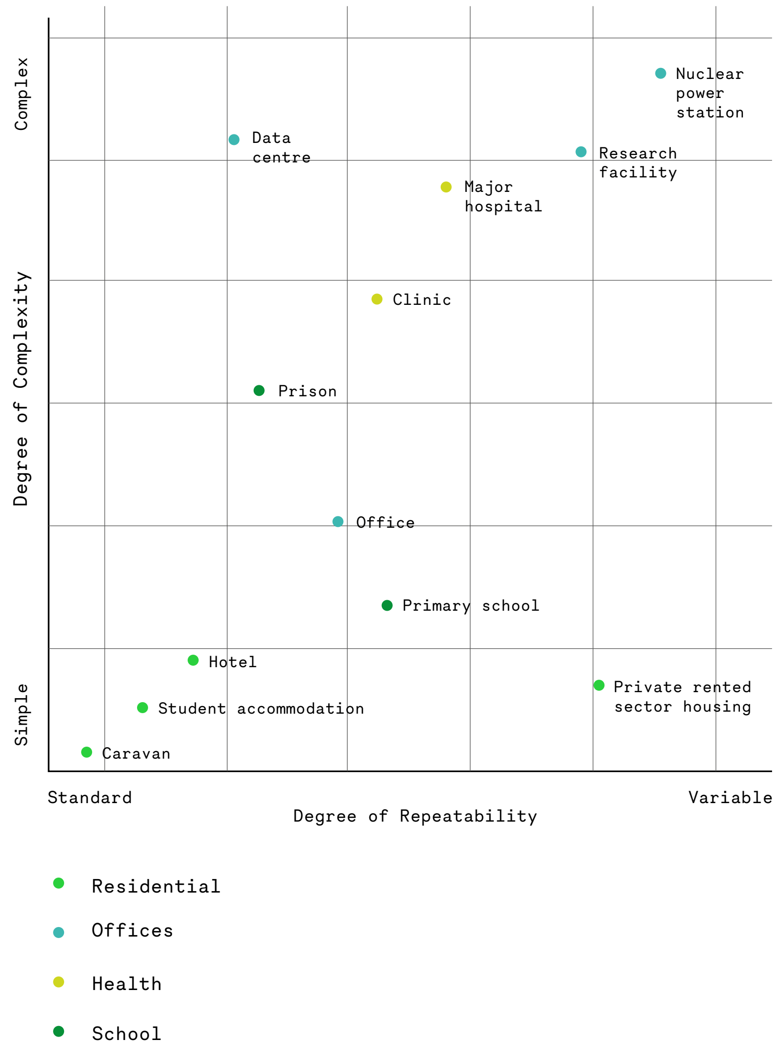
5. Level of repeatability

This would describe the overall degree of variation between the types of space or groupings of spaces within a particular building.

A typical housing scheme, for instance, will have a mix of unit types from small flats to large apartments, with a different layout on different floors, making it highly variable.

By contrast, student accommodation is highly standardised with little meaningful variation between the majority of spaces and floors.

Mapping complexity versus level of repeatability



Platforms can be mass customised

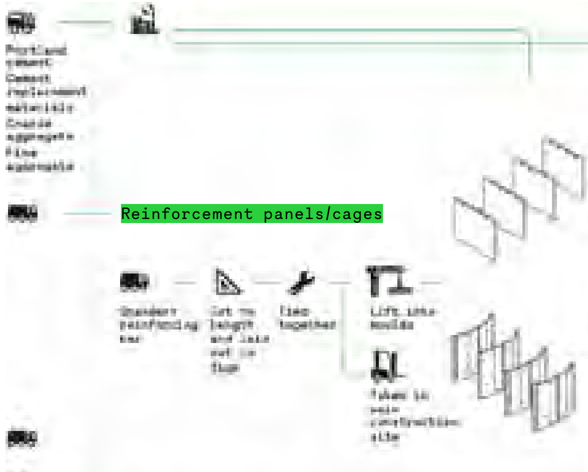
In order to provide solutions that are fine-tuned to specific localised needs and contexts, the creation of delivery platforms should accommodate sufficient levels of mass customisation.

Mass customisation is a manufacturing technique that combines the flexibility and personalisation of custom-made products with the low unit costs associated with mass production.

In order to deliver the broad range of spaces and assets required, some of the common components identified will need to have the option to be mass customised to meet the specific requirements of individual projects, such as site constraints or particular sector constraints.

Automotive manufacturing is an example of a successful implementation of this approach; computer manufacturing is another. Both of these sectors are characterised by the capability of the suppliers to provide customers with a personally configured product, with seemingly limitless possibilities of configuration. Neither party suffers significant additional cost or inconvenience for incurring such choice. In fact, the opposite is true.

MOJ PETP value stream mapping exercise for component creation using upskilled local labour



Pre-cast walls

The pre-cast walls seen here will be manufactured using accurate moulds and do not require cast in conduits etc., as such, the skill level required to make them is low and could be carried out by operatives trained for the task.
The walls can be cast upright in vertical moulds (in a space-efficient 'toaster rack' configuration) before being lifted into position.

Walls moved directly to final position on site

Structural 'core' assembly

This will form the structural 'core', with a riser on each side serving a pair of cells and the space in between forming the access corridor.
Manufacture would take place in a controlled environment, ideally on or very near site (in an existing facility or a temporary set up for this purpose).

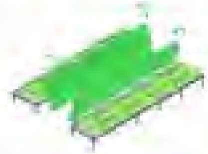
The majority of the assembly would be done at table-top height on accurate jigs, by operatives trained for the task.
Manufacturing-level quality assurance would be implemented, along with standard operating procedures etc. to ensure quality and consistency.

M&E manifolds set out in jigs (the spacing corresponds to storey heights).

Structural columns (standard SHS sections) connected with simple fixings.

Hot/cold water pipework / air ductwork installed between manifolds – as all of the 'intelligence' occurs within the manifold subassembly these are simple sections.

Drainage connections installed between manifold – these are pre-manufactured and include all of the connection points required for wash hand basin, shower and toilet pan. These could be produced by an existing manufacturer who may develop a 'special' product; the scale of the programme would justify developing tooling for this application and ensure consistent quality.



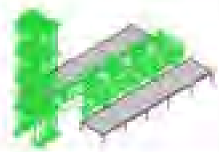
Opposing pairs of assemblies lifted onto their sides using an overhead crane or a simple lifting frame developed specifically for the task

Pairs of assemblies are ready to be connected together.

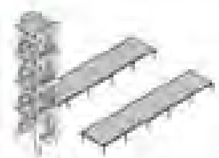
Profiled steel decking installed between pairs of assemblies – this will eventually create formwork for the structural slab (once concrete is poured in situ)

Temporary bracing installed – this will make the core section stiff enough to be lifted up and moved into its final position. The design of the bracing will allow operatives to move through the core in the temporary condition. Once the section of house block is complete the bracing can be removed and reused.

The core is now stiff enough to be raised upright. Core lifted using an overhead crane or a lifting frame developed specifically for the task



The completed core is now upright and stable and is ready to be lifted onto site in its final position



The completed core is removed and the process outlined in steps 1-11 can be repeated

Core moved directly to final position on site

This strategy will apply the thinking that underpins existing, successful models of mass customisation to the building-design and construction industry.

Three work strands will be underpinned by the use of Building Information Modeling (BIM) Level 2 standards, and in particular the use of Uniclass 2015 as a classification system to capture facilities, spaces, systems and products. This is described in more detail in the 'Procurement' section (132–79).

In order to achieve such mass-customised outcomes, consideration will be given to three scales:

Product assemblies


Interoperable
subassemblies

Component
parts

Product assemblies

We need to conduct market testing at the superstructure level to find popular or typical product configurations – the greatest commonalities and common choices across sectors. Then we need to understand the likely appetite for variation and increments of deviation from these baselines.

This identification and documentation of the functional typologies of spaces, departments and facilities that define publicly procured built assets across the most high-value sectors will provide briefing and guidance for the further work necessary to standardise and optimise spatial configurations across typologies.

Product assemblies for a primary school

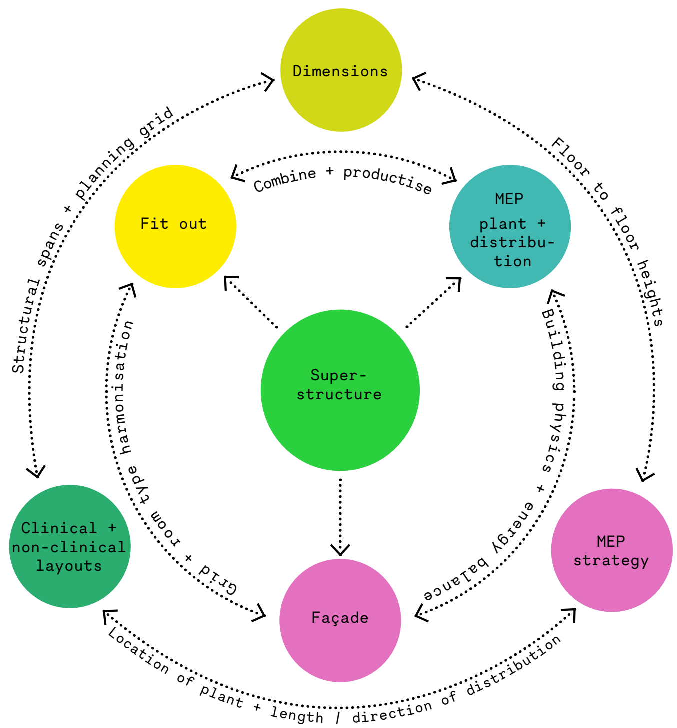
Interoperable subassemblies

Then we need to identify common constructional and operational subassemblies that can serve multiple typologies. These will include architectural, structural and MEP systems.

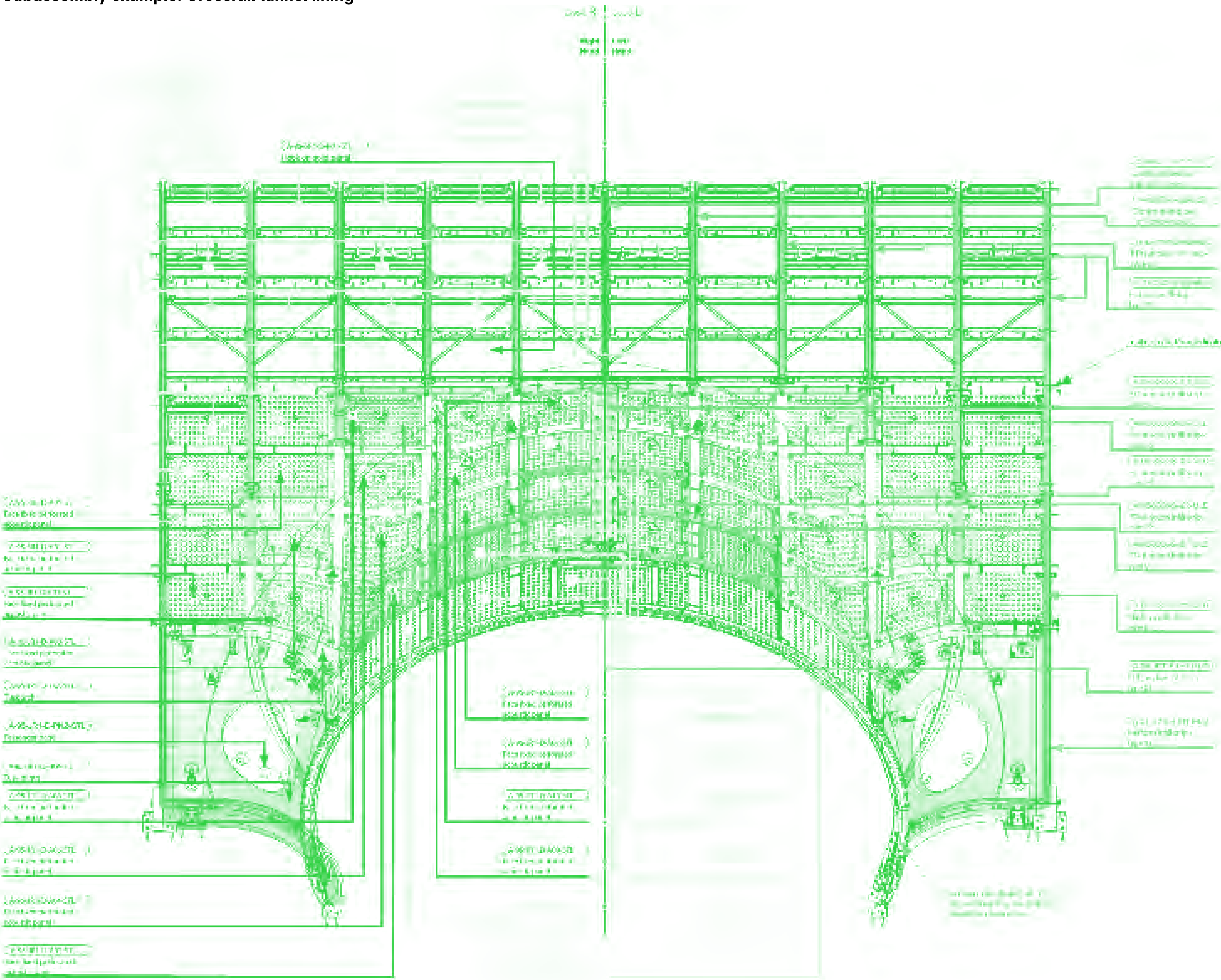
The comprehensive understanding of relationships between these aspects, such as their interoperability as of part of larger assemblies, will include the details of the specific assembly processes that are required.

This workstream will provide briefing and guidance for the further work necessary to standardise and optimise subassemblies to suit the product assemblies they will connect to.

Interoperable common construction and operational aspects



Subassembly example: Crossrail tunnel lining

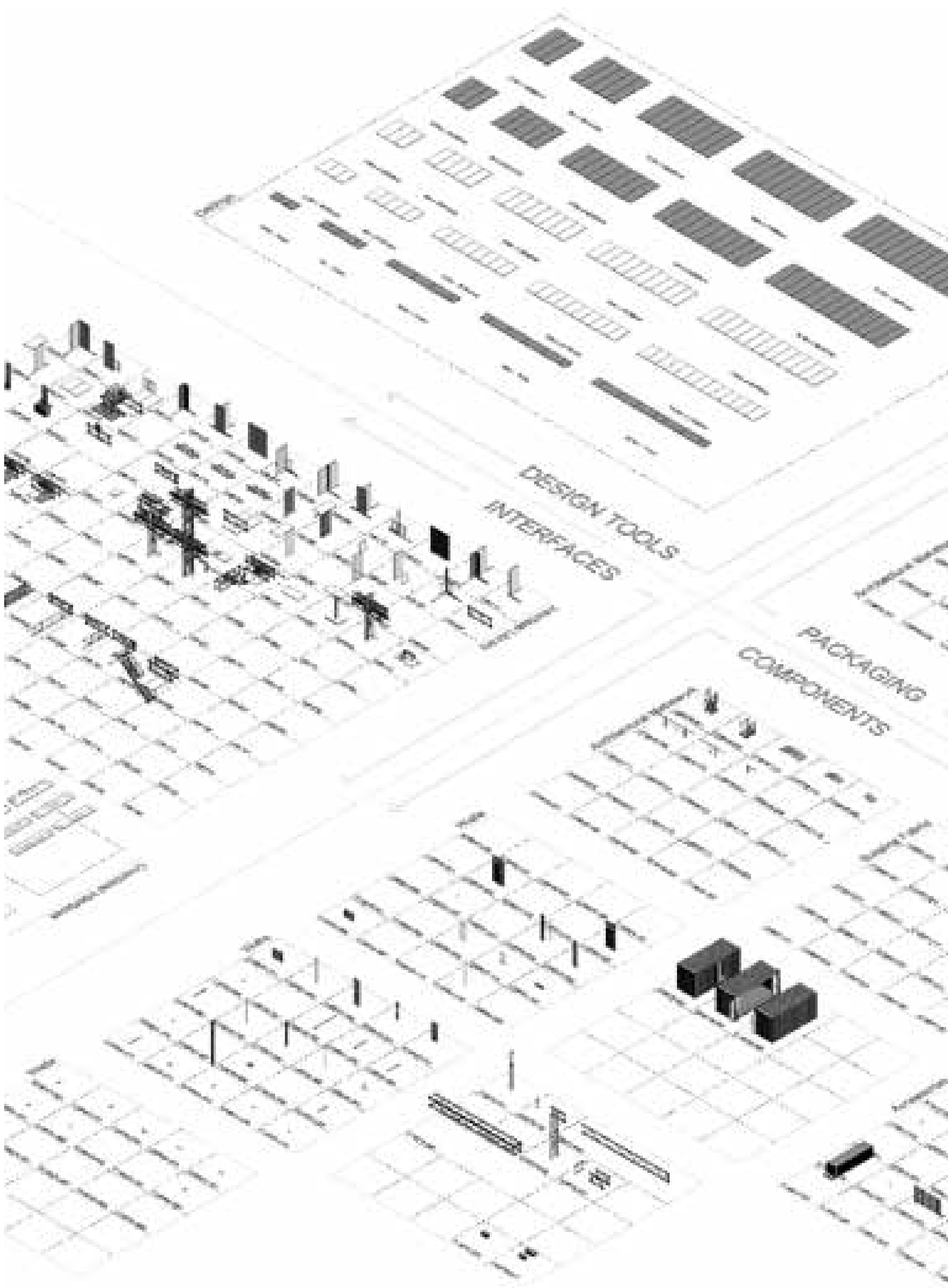


Component parts

This involves the identification of a parts library, which can populate and serve multiple subassemblies and combine to deliver the performance requirements of the product assemblies. This includes detailed knowledge of parts such as performance, costs and availability.

This work strand will provide briefing and guidance for the further work necessary to create a standardised 'parts library', including the means of cataloguing criteria for verification and validation required to maintain it (134-163).

Virtual warehouse of components for GSK 'Factory in a Box'



Platform characteristics need a lower barrier to entry

Work to date on developing the DfMA solutions for the MOJ PETP shows that

in order to be able to deploy DfMA at scale, the component design should have a low barrier to entry to existing supply chains, i.e. manufacturing the components should work with existing skills, processes and tools.

Platforms should therefore be made up from components with the following characteristics:

- Highly repeatable and able to be manufactured at scale by a wide supply chain
- Requires no specialist skills or equipment that is not widely available
- Able to be manufactured, assembled and pre-tested using rigorous quality assurance to maintain consistency across the programme (in construction and into operation)
- Could be manufactured and assembled using local, semi-skilled labour (following standard training in relevant tasks) to facilitate the creation of apprenticeships and expansion of manufacturing skillsets
- Require minimum materials handling and processing (which inevitably introduces waste and non-value-adding activity)
- Uses materials that are widely available in the United Kingdom
- Could be developed with MTC to optimise manufacturing processes (including adoption of some level of automation if appropriate and desirable)

Platform types

Based on the characteristics described, it is possible to hypothesise three platform types that might be appropriate for the majority of the space and asset types within the government estate:

Platform 1

A highly flexible and versatile system that would be highly customisable but with the following characteristic 'upper limits':

- Spanning capability up to 11m
- Variable structural loading capacity (depending on span) up to $5kN/m^2$
- Storey height up to 4m
- Building height up to 14 storeys
- Ability to work with a range of levels of interior fit out / mechanical and electrical services etc.

Platform 2

A 'domestic scale' system for mid- to high-rise housing (assuming that government investment is more likely to be in mid- to high-rise housing than low rise, low density):

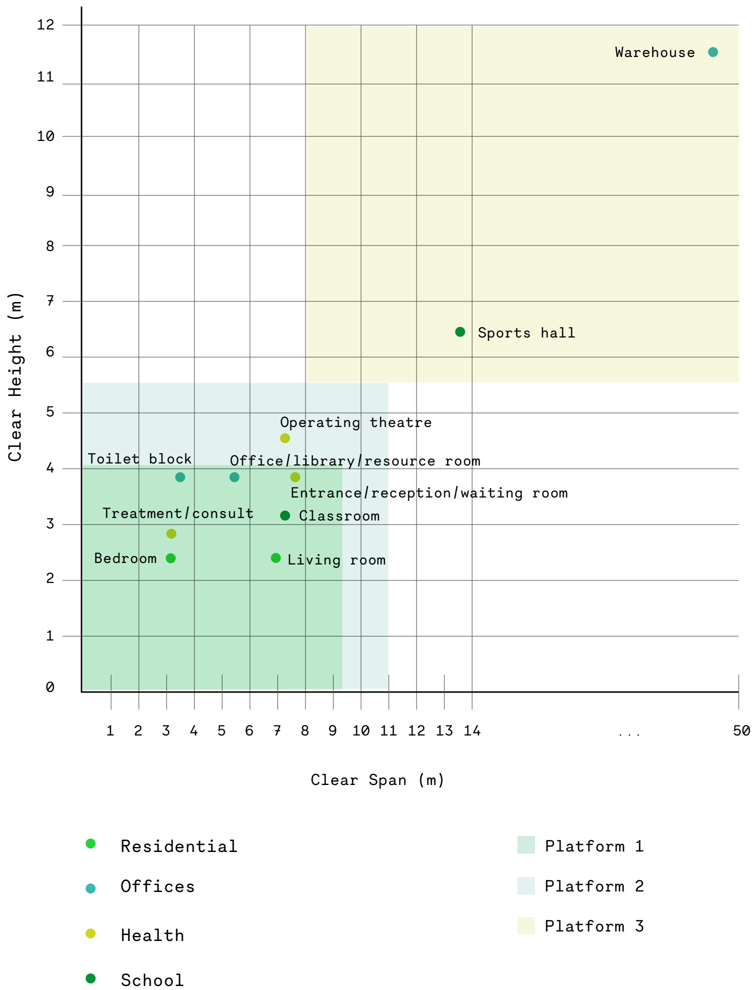
- Spanning capability up to 8m
- Loading capacity up to $2kN/m^2$
- Storey height up to 4m
- Building height up to 25 storeys
- Ability to work with a range of levels of domestic interior fit out / mechanical and electrical services etc.

Platform 3

A 'large spaces' system for buildings such as sports halls, storage/warehouse/distribution facilities etc.:

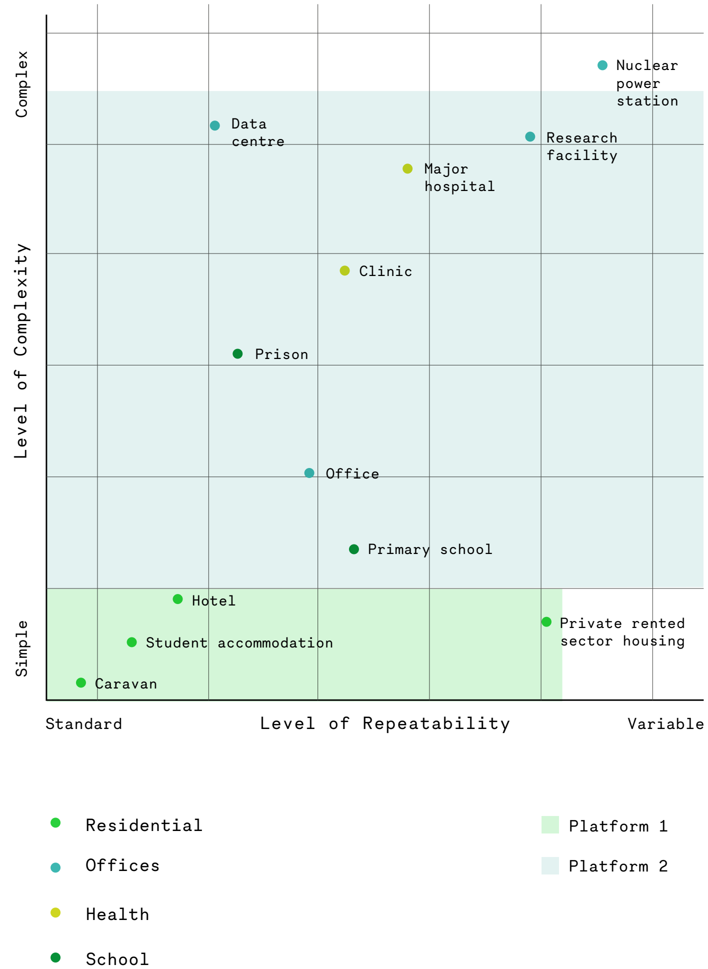
- Spanning capability up to 50m
- Loading capacity on ground floor slab, with mezzanine floor up to $5kN/m^2$
- Clear height up to 12m
- Building height up to 1 storey
- Ability to work with a range of levels of domestic interior fit out / mechanical and electrical services etc.

Three platform types

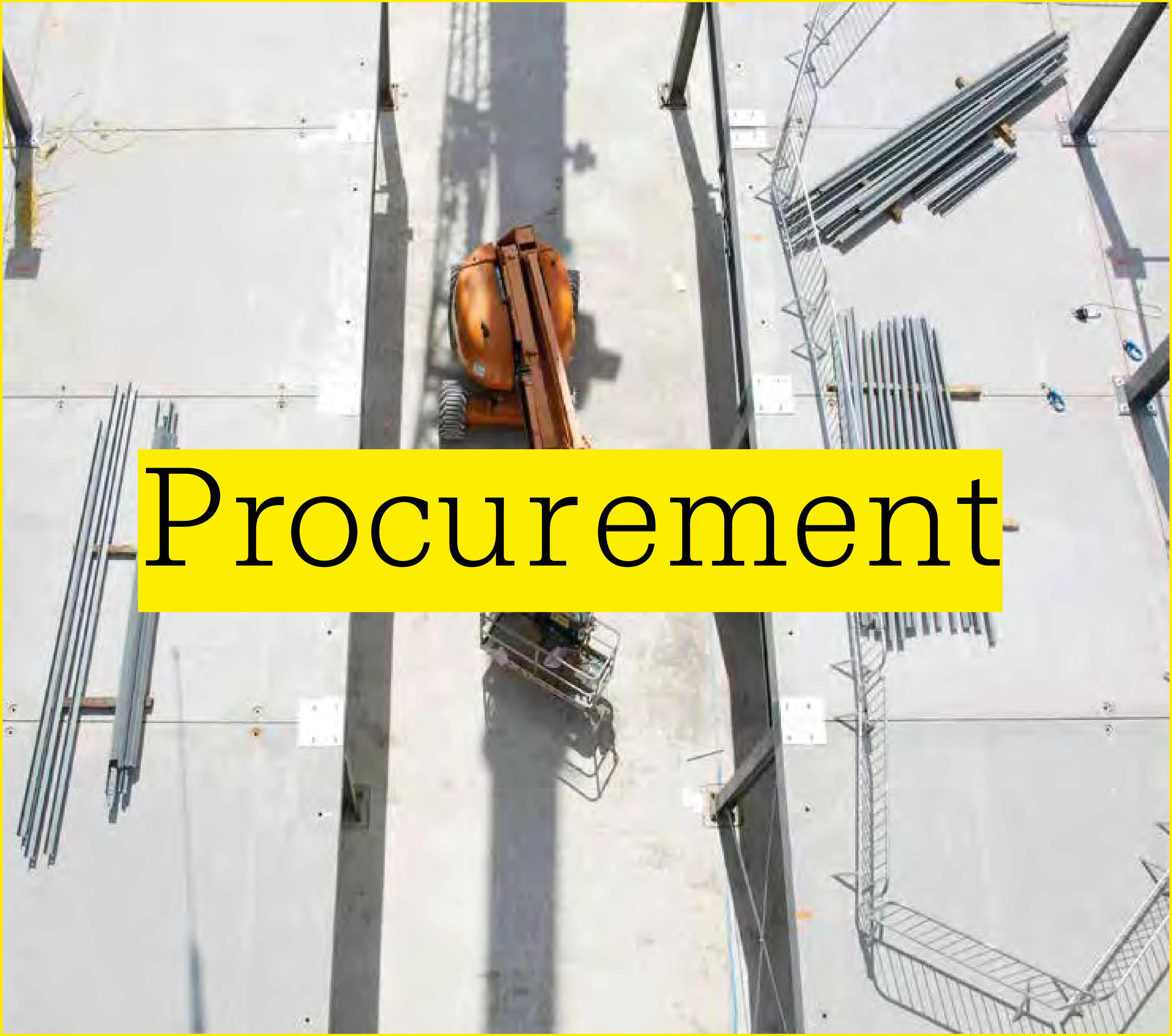


In fact, this early-stage assessment shows that there are very few building types that would not be adequately serviced using two platform types.

The two key platform types that service most assets



Procurement



Classification

The adoption of Uniclass will be critical to the standardisation of design and delivery.

Standardisiation requires the digitisation of data, which will in itself have three benefits:

- The creation of a quality-assurance process that makes it possible to trace and record critical data from design through to operation. Uniclass provides the common thread that can link every scale of the physical elements with the functional and spatial requirements of a facility.
- Enabling digital models and configurators to faithfully simulate behaviour of components, subassemblies or processes. The more data we can add to our digital twins, the more able they will be to accurately simulate and test properties such as stresses and thermal properties.
- The ability to have a common frame of reference for describing buildings, spaces, systems and components. Uniclass 2015 is a unified classification system for the construction industry, divided into a set of tables which link ‘spaces’ and ‘physical systems’. These can be used to categorise information for costing, briefing etc.; for asset management and facilities-management information ‘in use’ data; as well as when preparing specifications or other production documents.

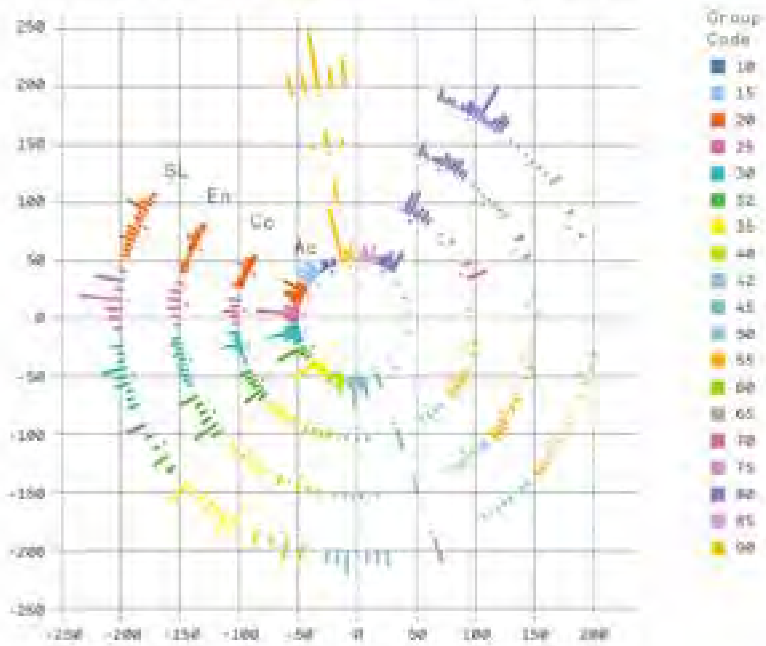
The tables are:

Ac -	**Activities**
Co -	**Complexes**
En -	**Entities**
SL -	**Spaces/locations**
EF -	**Elements/functions**
Ss -	**Systems**
Pr -	**Products**

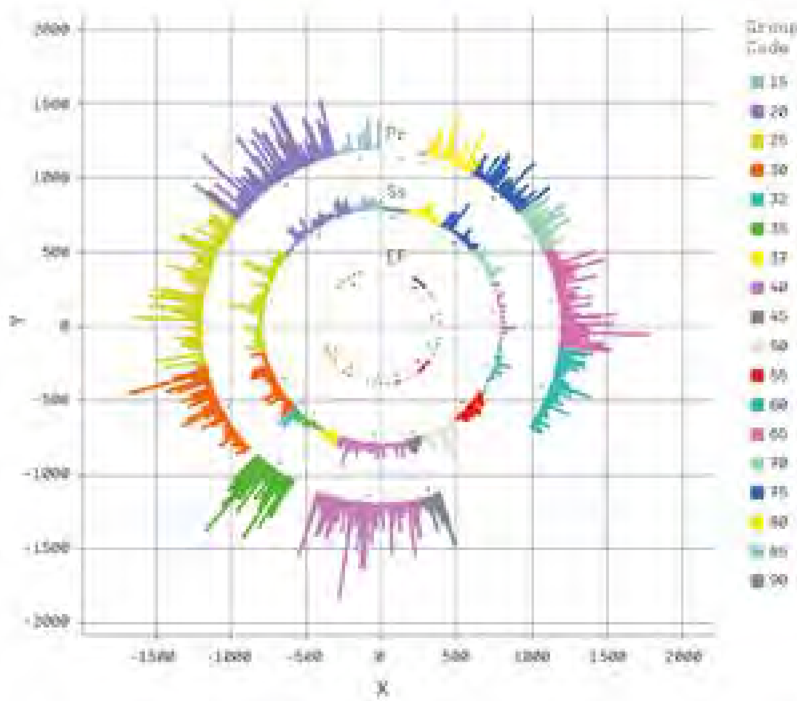
Delivery phase:

CA -	**Construction aids**
FI -	**Form of information**
PM -	**Project management**

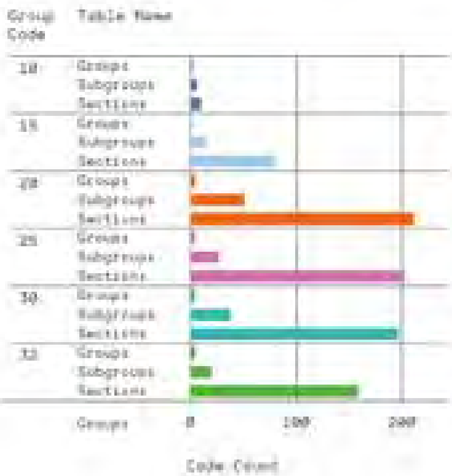
Code counts per group for tables AC, Co, En and SL



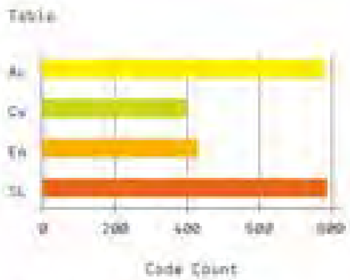
Code counts per group for tables EF, Ss and Pr



Code Count per group



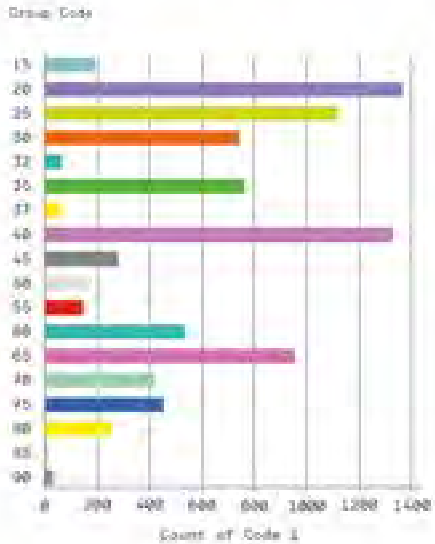
Code Count per table



Example data visualisation for

Ac - **Activities**
Co - **Complexes**
En - **Entities**
SL - **Spaces/ locations**

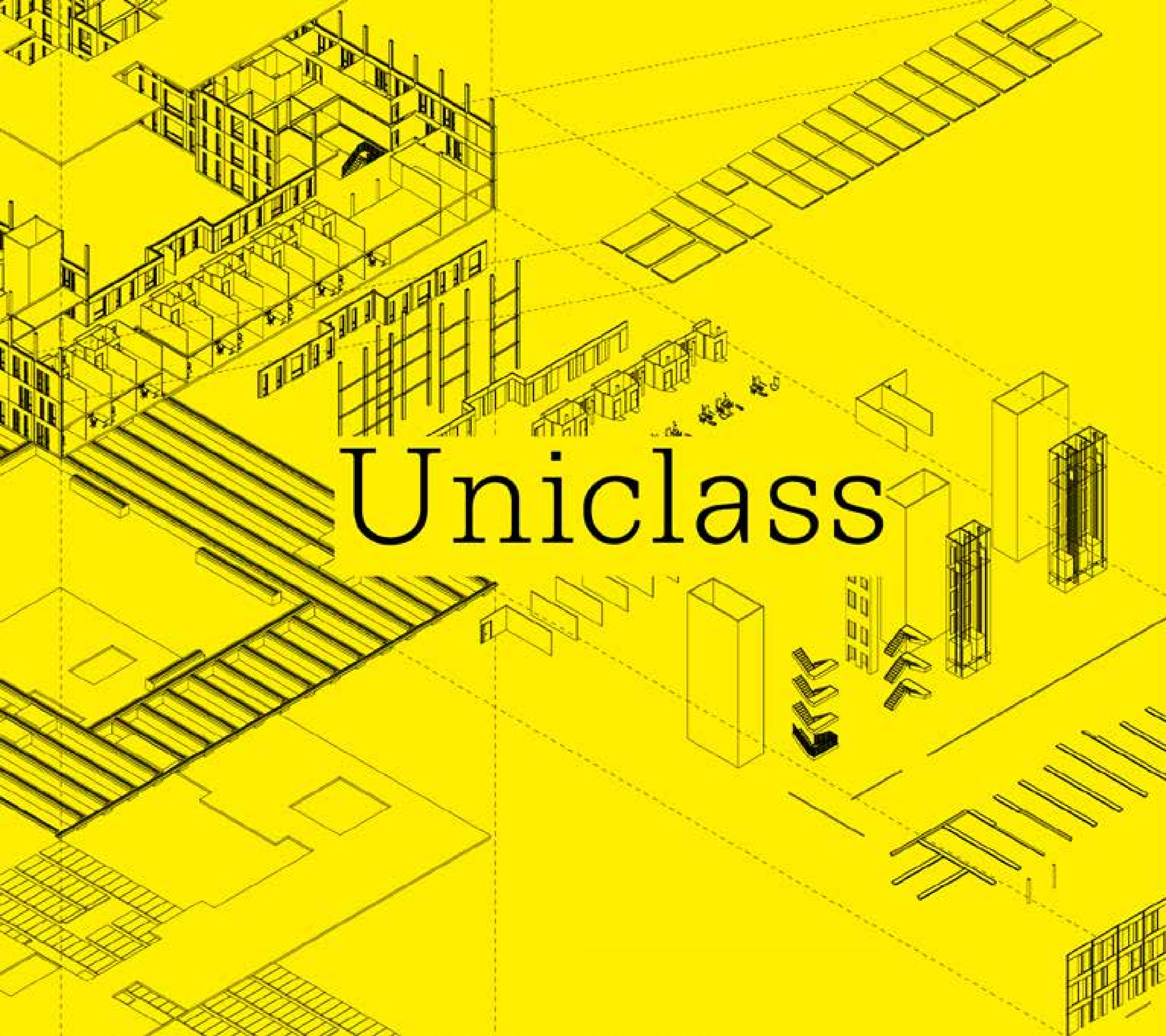
Code Count per group



Code Count per table

Example data visualisation for

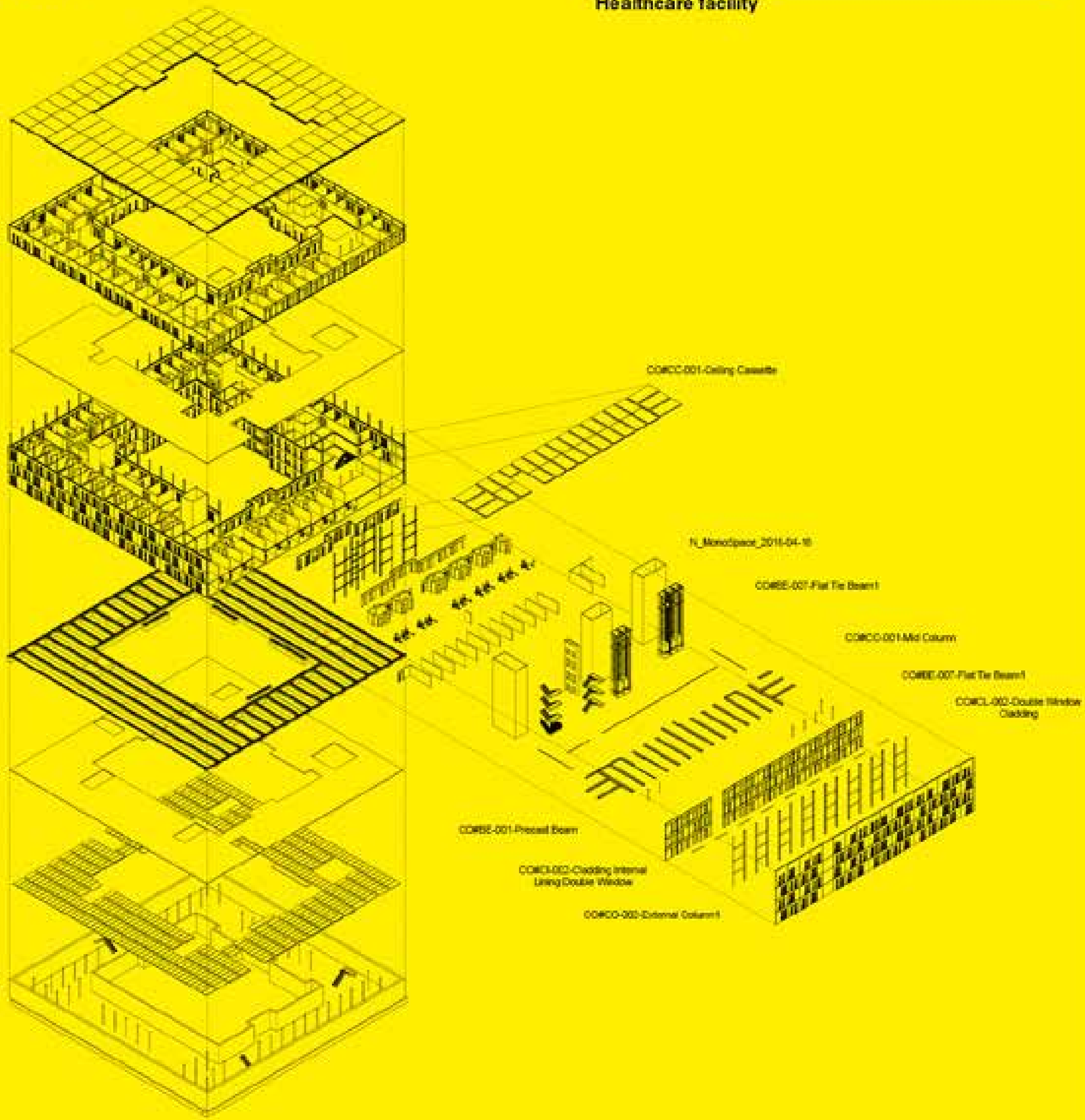
EF - **Elements/ functions**
Ss - **Systems**
Pr - **Products**

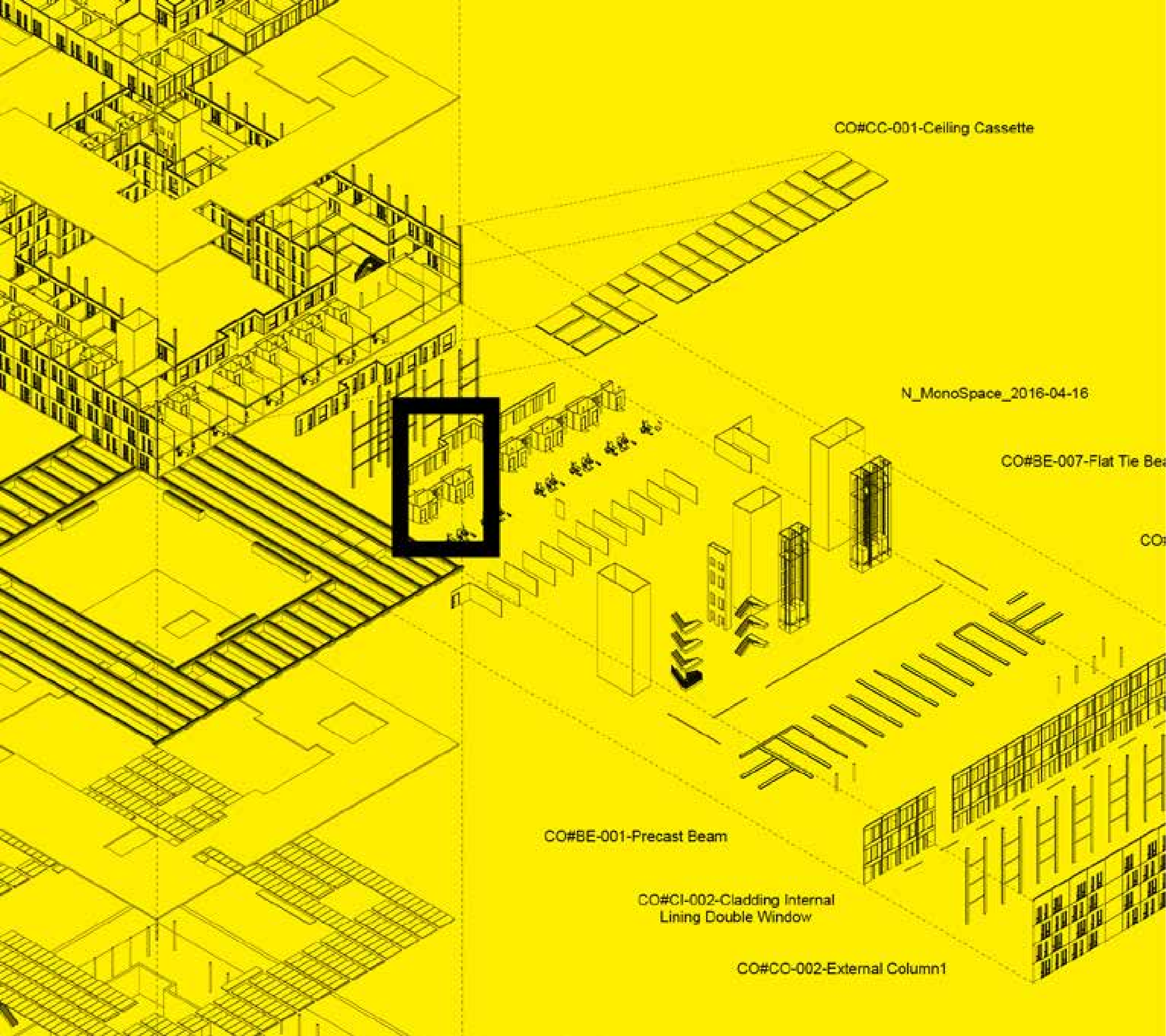

Uniclass

Uniclass classification – at facility level

Ac -	Activities
Ac_25_30	Scientific + laboratory activities
Ac_25_90	Worship activities
Ac_35	Medical, health, welfare + sanitary activities
Ac_35_10	Medical activities
Ac_35_10_08	Birthing
Ac_35_10_10	Burns treating
Ac_35_10_15	Consulting
Ac_35_10_31	First aiding
Ac_35_10_36	Hearing testing
Ac_35_10_39	Hydrotherapy
Ac_35_10_42	Intensive caring
Ac_35_10_43	Isolation caring
Ac_35_10_51	Medical scanning
Ac_35_10_53	Midwifery
Ac_35_10_57	Nursing
Ac_35_10_58	Occupational therapy
Ac_35_10_59	Operating
Ac_35_10_64	Pharmaceutical dispensing
Ac_35_10_65	Phototherapy
Ac_35_10_66	Physiotherapy
Ac_35_10_70	Radiography
Ac_35_10_71	Radiotherapy
Ac_35_10_74	Rehabilitating
Ac_35_10_76	Screening
Ac_35_50	Welfare activities
Ac_35_50_21	Daycare
Ac_35_50_42	Infant caring
Ac_35_60	Food-management activities
Ac_35_60_16	Cooking
Ac_35_60_30	Food preparation
Ac_35_60_31	Food serving
Co	Complexes
Co_35	Medical, health, welfare and sanitary complexes
Co_35_10	Medical complexes
Co_35_10_37	Hospital complexes
En -	Entities
En_35	Medical, health, welfare + sanitary entities
En_35_10	Medical entities
En_35_10_10	Medical buildings
SL -	Spaces/locations
SL_35	Medical, health, welfare and sanitary spaces
SL_35_10	Medical spaces
↓	
EF -	Elements / functions
Ss -	Systems
Pr -	Products
↓	

Healthcare facility





CO#CC-001-Ceiling Cassette
N_MonoSpace_2016-04-16
CO#BE-007-Flat Tie Bea
CO#BE-001-Precast Beam
CO#CI-002-Cladding Internal
Lining Double Window
CO#CC-002-External Column1

Uniclass classification – at room level

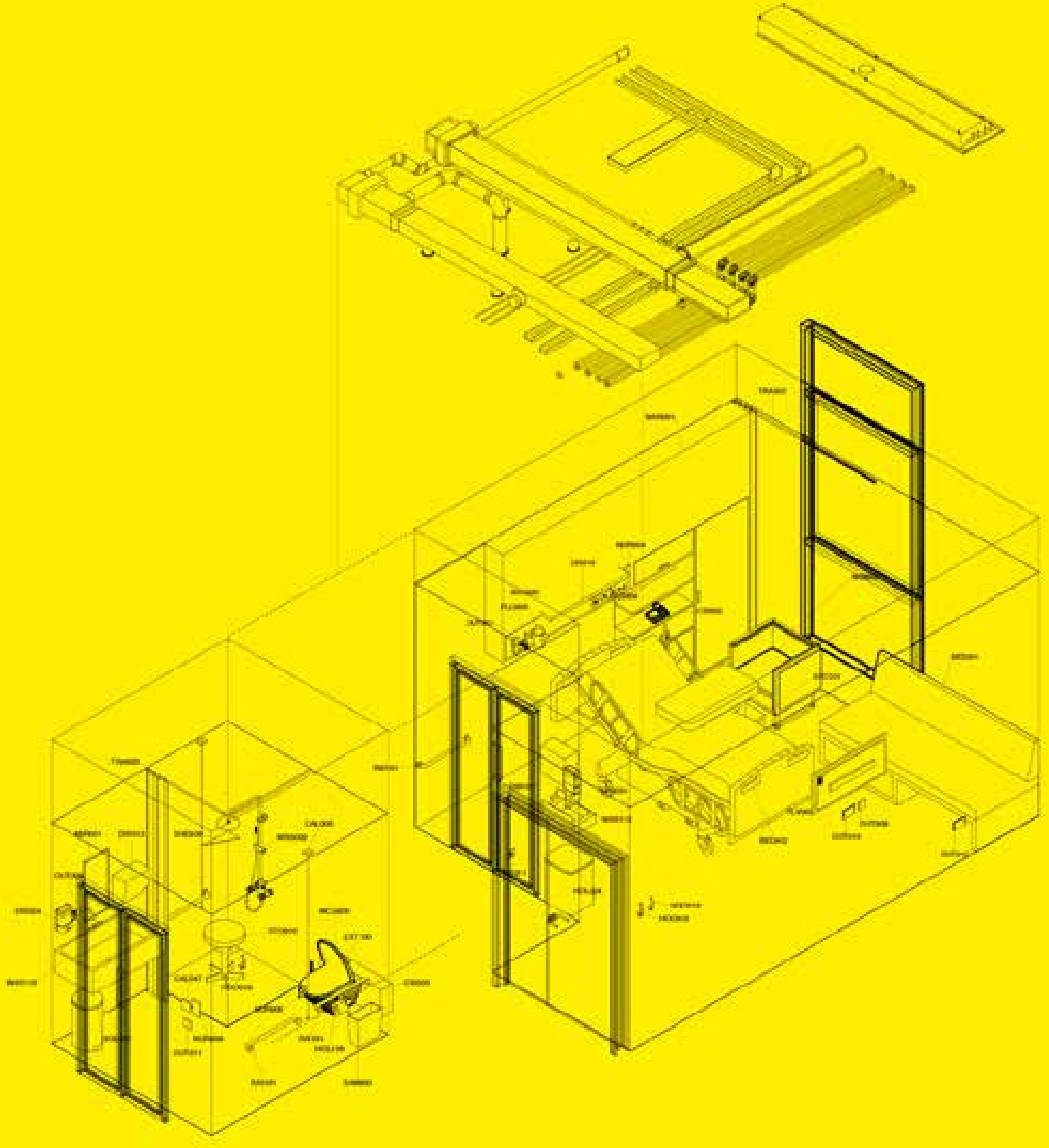
Ac -	Activities
Ac_35	Medical, health, welfare and sanitary activities
Ac_35_10	Medical activities
Ac_35_10_57	Nursing
Ac_35_60_31	Food serving
Ac_45_10_79	Sleeping
Ac_35_80	Sanitary activities
Ac_35_80_07	Bathing
Ac_35_80_80	Showering
SL -	Spaces/locations
SL_35	Medical, health, welfare and sanitary spaces
SL_35_10	Medical spaces
SL_35_10_53	Medical treatment spaces
SL_35_10_96	Wards
SL_45_10_09	Bedrooms
EF -	Elements/functions
EF_25	Wall and barrier elements
EF_25_10	Walls
EF_25_30	Doors and windows
EF_30_20	Floors
EF_55	Piped supply functions
EF_55_05	Gas extraction and treatment
EF_55_20	Gas supply
EF_55_70	Water supply
EF_60	Heating, cooling and refrigeration functions
EF_60_40	Space heating and cooling
EF_65	Ventilation and air conditioning functions
EF_65_40	Ventilation
EF_65_80	Air conditioning
EF_70	Electrical power and lighting functions
EF_70_30	Electricity distribution and transmission
EF_70_80	Lighting
EF_75	Communications, security, safety and protection functions
EF_75_10	Communication
EF_75_30	Signalling
EF_75_40	Security
EF_75_50	Safety and protection
Ss -	Systems
Ss_25	Wall and barrier systems
Ss_25_10	Framed wall systems
Ss_25_10_30	Framed partition systems
Ss_25_10_30_35	Gypsum board partition systems

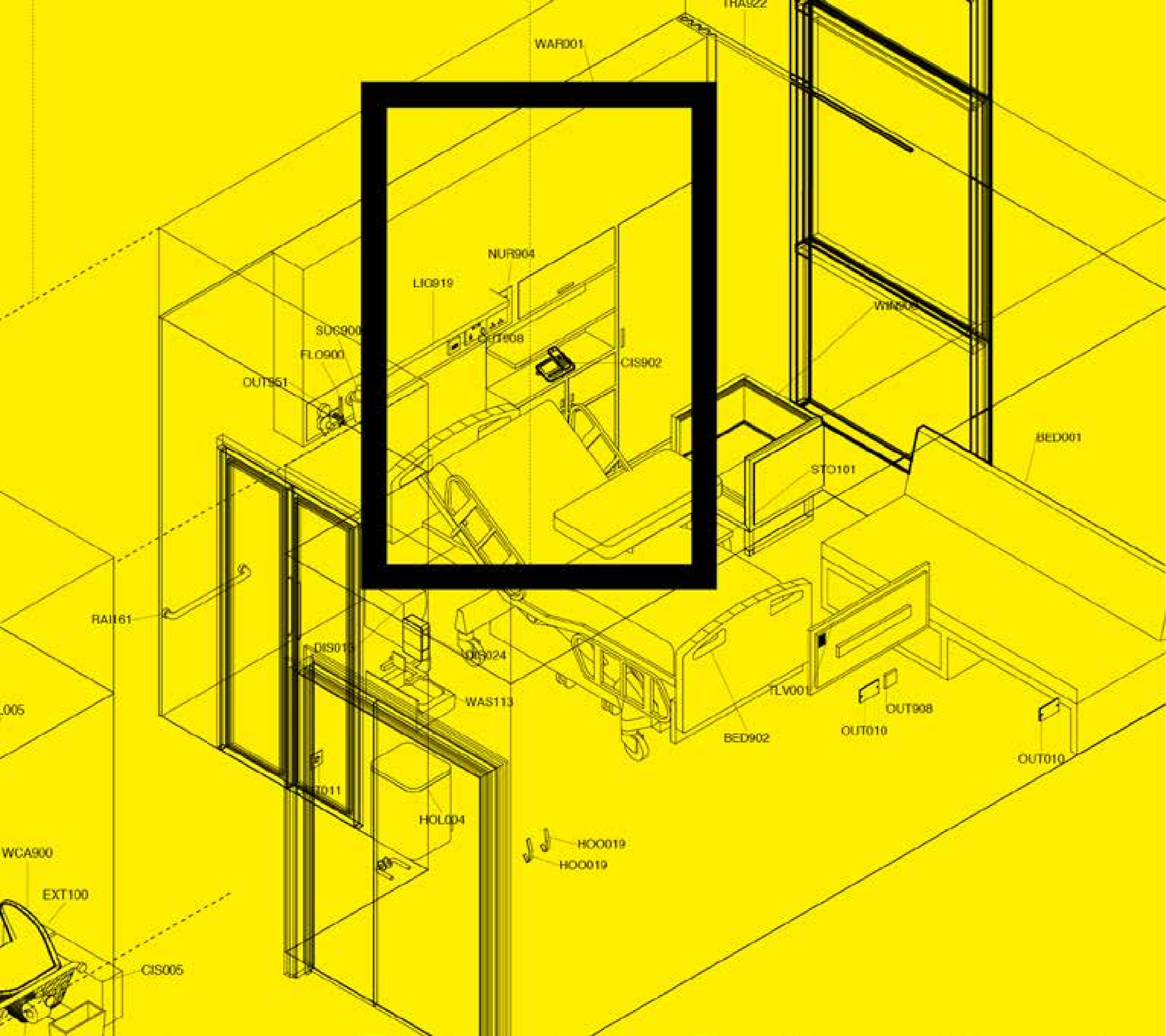
↓

Pr -	Products

↓

Bedroom and en suite bathroom



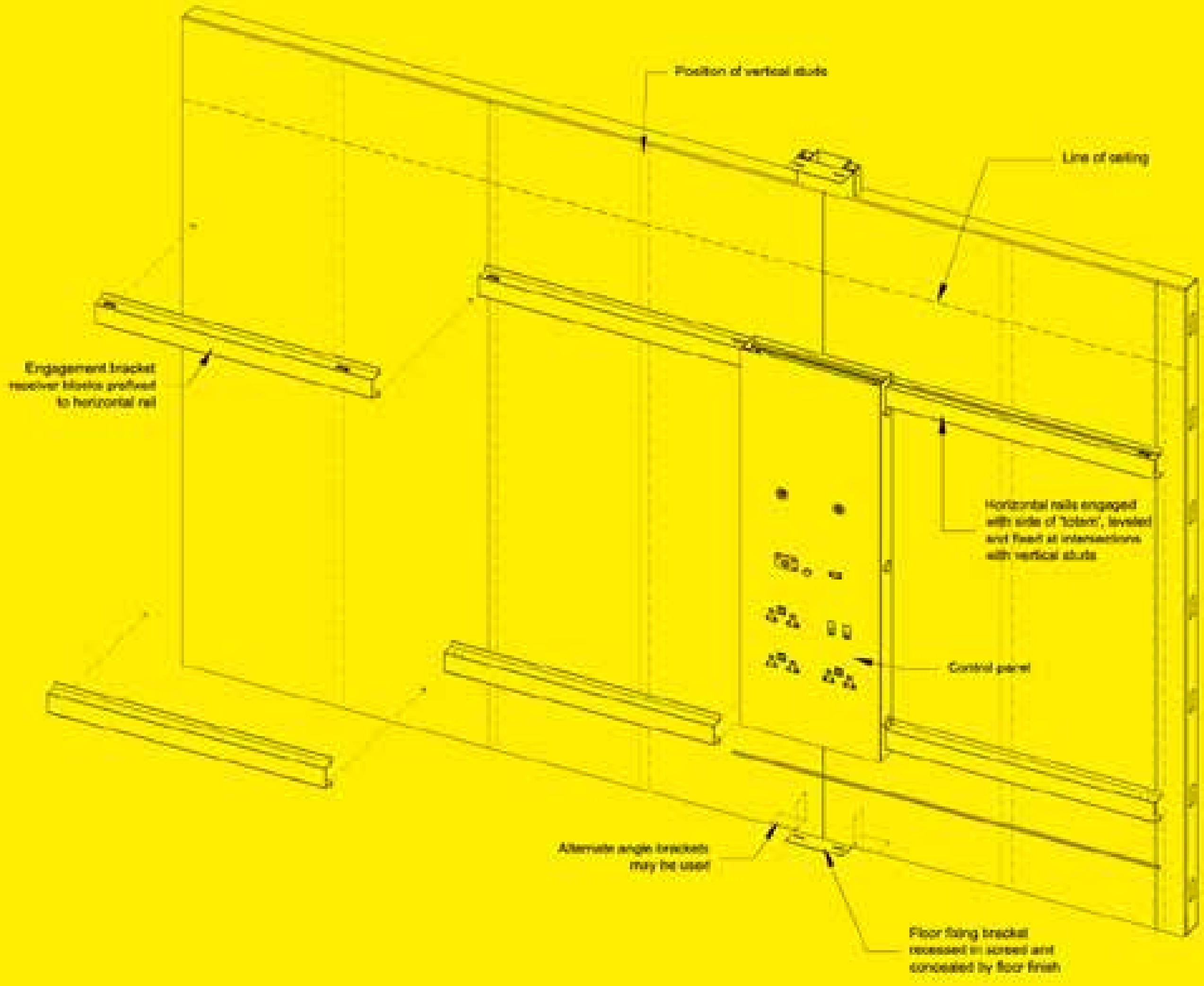

WAR001
NUR904
LIG919
SUC900
FLO900
OUT951
OUT908
CIS902
BED001
STO101
RAI161
DIS015
DIS024
WAS113
TLV001
OUT908
OUT010
BED902
OUT010
HOL004
HOO019
HOO019
WCA900
EXT100
CIS005

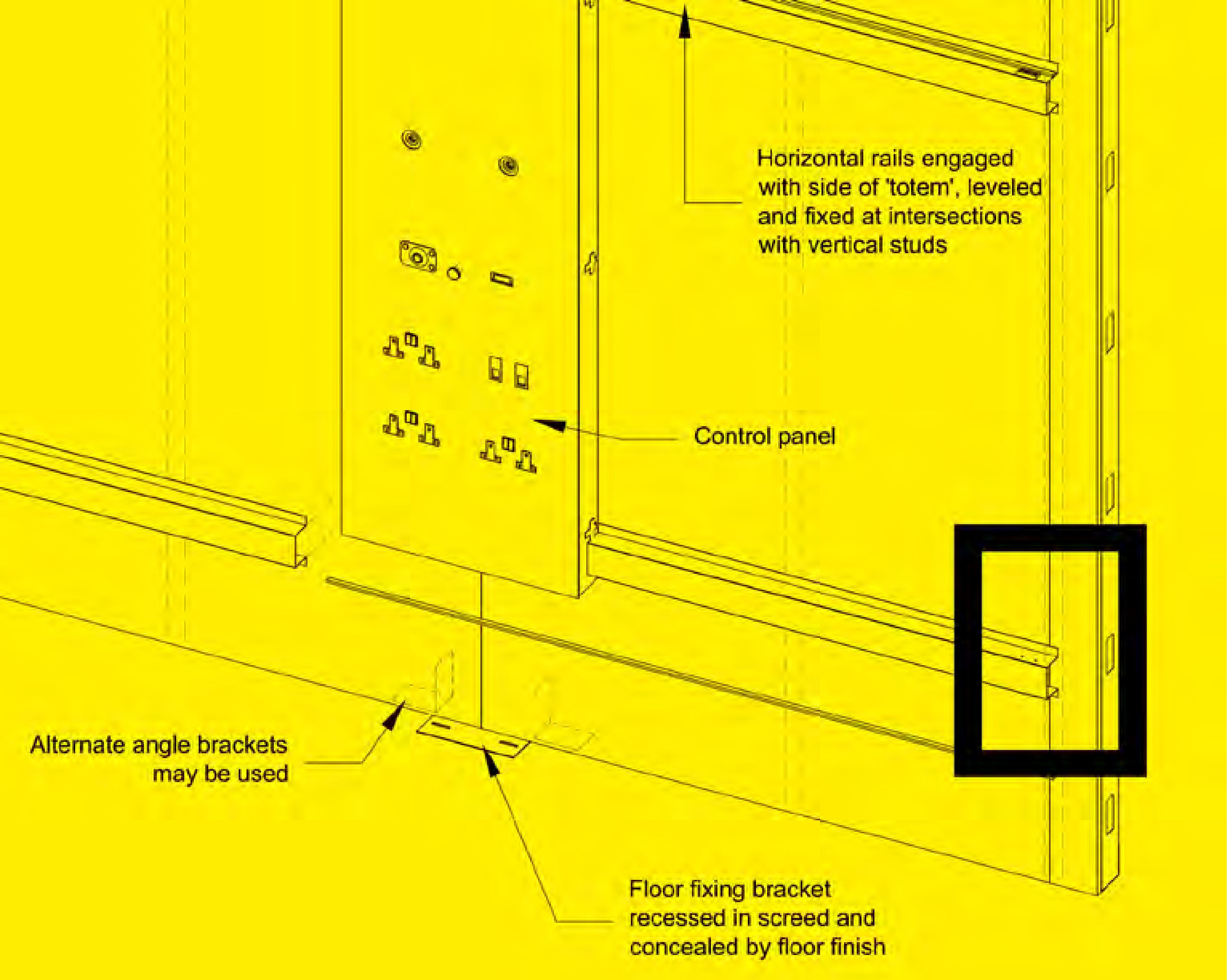
Fixtures, fittings and systems level

Ss -	Systems
Ss_25_25	Wall-lining systems
Ss_25_25_45	Lining and casing systems
Ss_25_25_45_25	Duct and wall panel-lining systems
Ss_25_25_45_90	Timber board wall-lining systems
Ss_40_50	Medical, health and welfare FF+E systems
Ss_40_50_50	Medical and health FF+E systems
Ss_40_50_50_37	Hospital ward FF+E systems
Ss_55_20_51	Medical gas supply systems
Ss_55_20_51_03	Medical anaesthetic gas scavenging systems
Ss_55_20_51_27	Medical entonox supply systems
Ss_55_20_51_36	Medical helium/ oxygen mixture supply systems
Ss_55_20_51_56	Medical nitrous oxide supply systems
Ss_55_20_51_57	Medical nitrous oxide/ oxygen mixture supply systems
Ss_55_20_51_59	Medical oxygen supply systems
Ss_70	Electrical systems
Ss_70_30_80	Small power systems
Ss_70_30_80_45	Low-voltage small power systems with prefabricated wiring
Ss_70_80	Lighting systems
Ss_70_80_33	General space lighting systems
Ss_70_80_33_33	General lighting systems with prefabricated wiring
Ss_75	Communications, security, safety, control and protection systems
Ss_75_10	Communications systems
Ss_75_10_21	Data distribution and telecommunications systems
Ss_75_10_21_21	Data distribution systems
Ss_75_10_21_88	Telecommunications systems
Ss_75_50	Communication, safety and protection systems
Ss_75_50_11	Call and alarm systems
Ss_75_50_11_57	Nurse call systems
Pr -	Products

↓

Wall panel incorporating medical gas outlets and power/data sockets



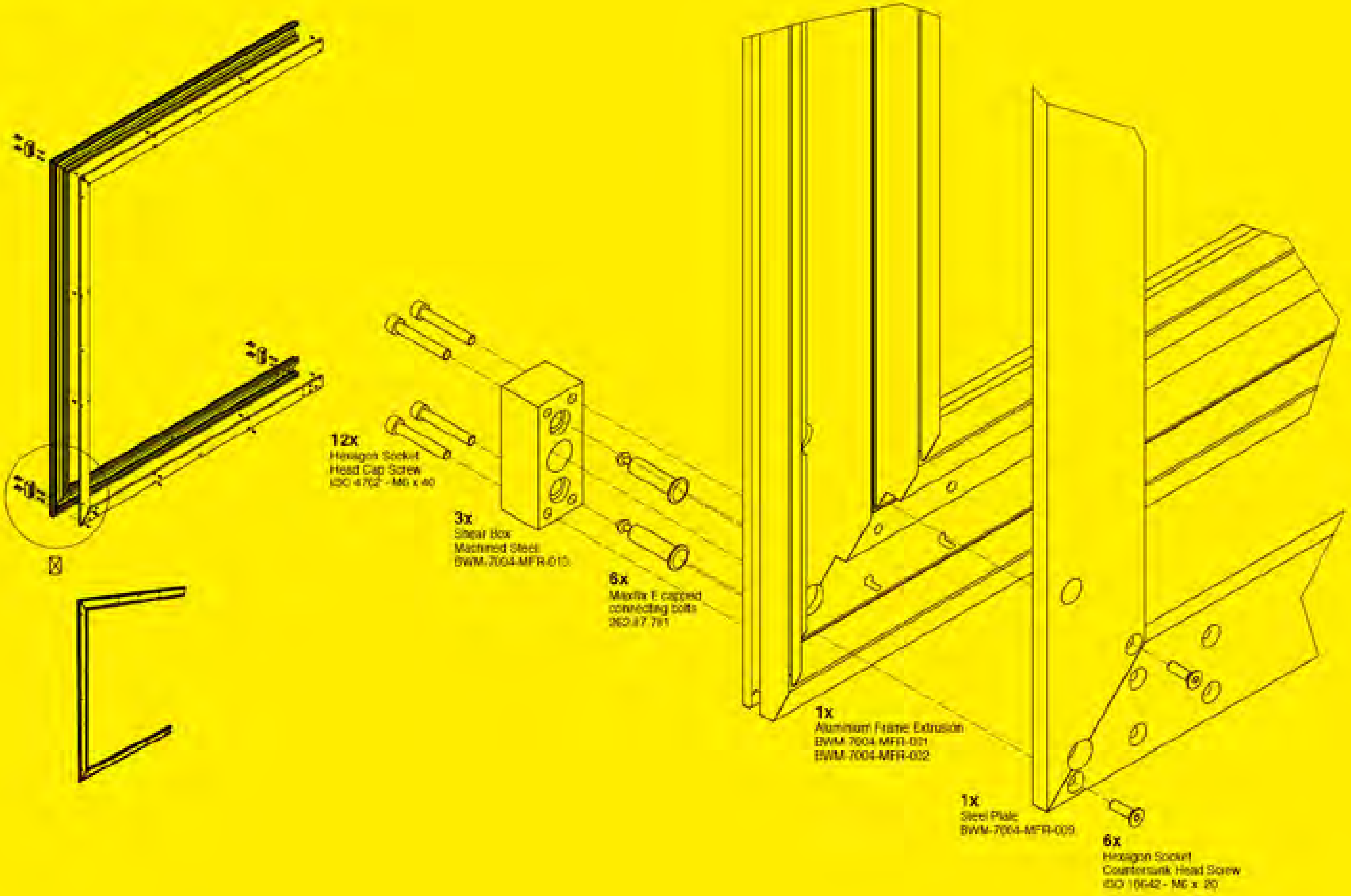


Horizontal rails engaged with side of 'totem', leveled and fixed at intersections with vertical studs
Control panel
Alternate angle brackets may be used
Floor fixing bracket recessed in screed and concealed by floor finish

Component level

Individual components making up the wall panel

```
Pr -              Products
Pr_20             Structure and general products
Pr_20_29          Fastener products
Pr_20_29_76       Screws
Pr_20_29_76_81    Socket screws
```



Beyond Uniclass: Manufacturers' data on standard products

The Uniclass component data can be linked to individual manufacturers' data.

There are moves within manufacturing to standardise how manufacturers capture, store and label this data, so that data is directly comparable across manufacturers. This is described in more detail in a recent document *Product Data Definition*.*

LEXiCON, hosted by the Construction Products Association, will implement the methodology set out in the *Product Data Definition* document and will facilitate the capture of the following information relating to products:

- Essential requirements for the Harmonised European Standards (hENs)
- Requirements from other standards (e.g. relevant ISO, EN or BS standards other than those captured above)
- Industry-recognised documents
- Mandated requirements for a specific sector or application (e.g. NRM for Chartered Surveyors)
- Non-mandated but recognised within a specific sector (e.g. CIBSE Guide M)
- Industry-agreed and recognised (e.g. identified by a professional institute, trade association or cross-industry group)
- User-defined additional terms proposed for approval and wider adoption

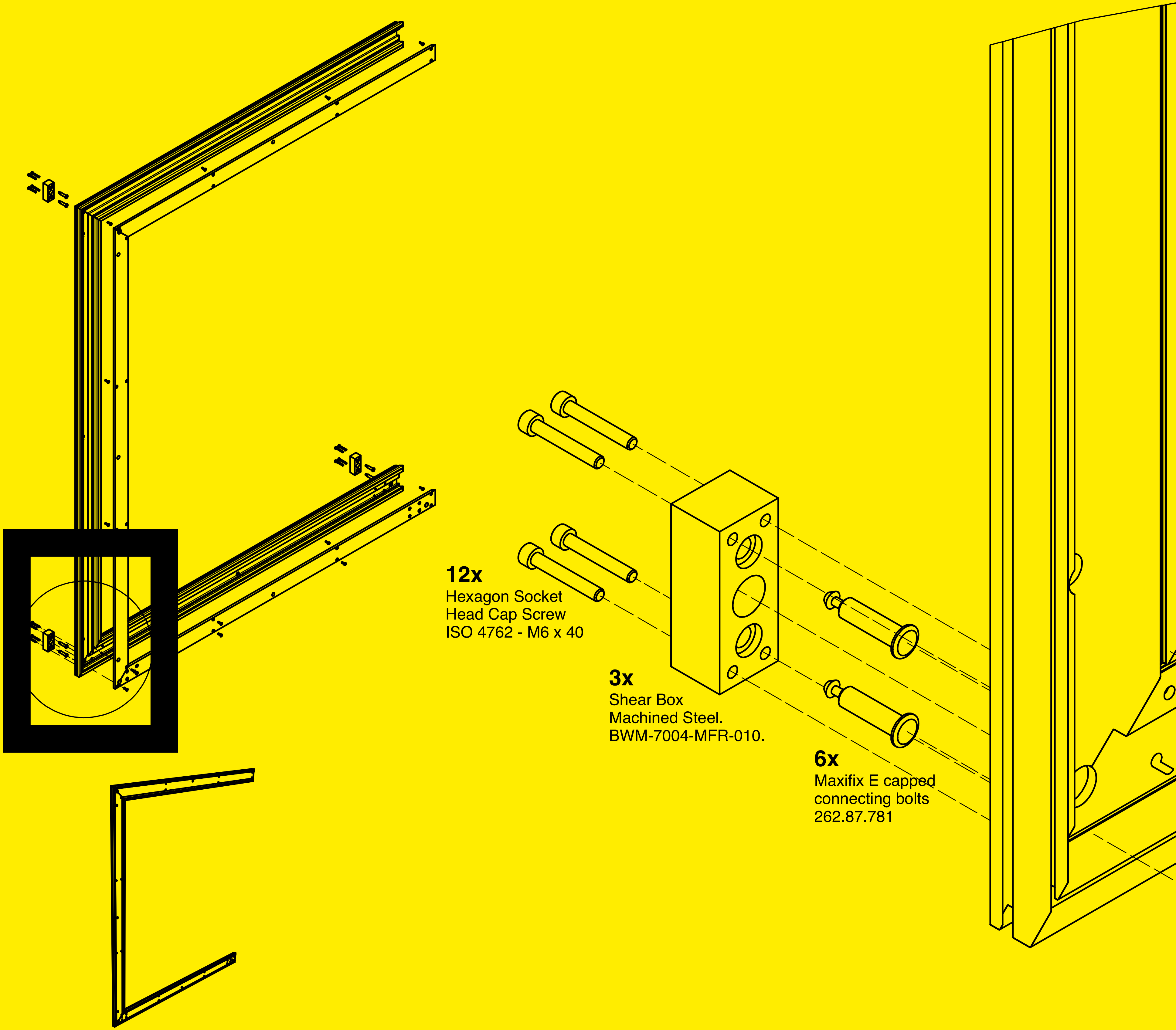
* Steve Thompson, *Product Data Definition – A technical specification for defining and sharing structured digital construction product information* (London: Department of Business, Innovation and Skills, 2016), https://www.thefis.org/wp-content/uploads/2016/09/product-data-definition_v2.pdf.

An approved manufacturers' data table of standard components

Template Reference	1234
Classification	Pr_20_76_52_15_Carbon steel hot finished hollow sections
Description	Hot finished structural hollow sections - example
Template Author	Me
Template Status	Approved

Template Revision	1
Template Revision Date	2016-04-12
Completion Revision	1
Completion Revision Date	2016-04-12
Relevant Authority	A N Other

parameter	value	units	description	Measure	Responsibility	Unique identifier	Information Sets
Tolerances		mm	Tolerances on dimensions and shape for hot finished structural hollow sections	Length	Manufacturer	0ZMi60qRqHu000025QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Elongation		%	Elongation in accordance with Tables A.3 and B.3 of BS EN 10210-1:2006	Ratio	Manufacturer	0ZMi60qRqHu000026QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Tensile strength		N/mm²	Tensile strenght in accordance with Tables A.3 and B.3 of BS EN 10210-1:2006	Force	Manufacturer	0ZMi60qRqHu000027QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Yield strength		N/mm²	Yield strenght in accordance with Tables A.3 and B.3 of BS EN 10210-1:2006	Force	Manufacturer	0ZMi60qRqHu000028QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Impact strength		N/mm²	Impact strenght in accordance with Tables A.3 and B.3 of BS EN 10210-1:2006	Force	Manufacturer	0ZMi60qRqHu000029QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Weldability			CEV value specified, in accordance with Tables A.2 and B.2 of BS EN 10210-1:2006	-	Manufacturer	0ZMi60qRqHu000030QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Durability			in accordance with Clause 6.7.2. of BS EN 10210-1:2006	-	Manufacturer	0ZMi60qRqHu000031QrE$V	BS EN 10210 1_2006 EssentialCharasteristics
Outside diameter		mm	Outside diameter D of hollow section	Length	Structural Engineer	0ZMi60qRqHu000032QrE$V	BS EN 10210 1_2006 NonEssential
External perimeter		mm	External perimeter of square, rectangular or eliptical section	Length	Structural Engineer	0ZMi60qRqHu000033QrE$V	BS EN 10210 1_2006 NonEssential
Steel grade			Steel name, e.g. S355NH	-	Structural Engineer	0ZMi60qRqHu000034QrE$V	BS EN 10210 1_2006 NonEssential
Cross sectional Area		cm²	Cross sectional area of the section	Area	Structural Engineer	0ZMi60qRqHu000035QrE$V	CircularHollowSection_Geometry
Thickness		mm	Specified thickness	Length	Structural Engineer	0ZMi60qRqHu000036QrE$V	CircularHollowSection_Geometry
Mass		kg/m	Mass per unit length	Mass	Structural Engineer	0ZMi60qRqHu000037QrE$V	CircularHollowSection_Performance
Second Moment of Area		cm⁴	Second Moment of Area	Moment of Inertia	Structural Engineer	0ZMi60qRqHu000038QrE$V	CircularHollowSection_Performance
Radius of Gyration		cm	Radius of Gyration	Length	Structural Engineer	0ZMi60qRqHu000039QrE$V	CircularHollowSection_Performance
Elastic Section Modulus		cm³	Elastic Section Modulus	Section Modulus	Structural Engineer	0ZMi60qRqHu000040QrE$V	CircularHollowSection_Performance
Plastic Section Modulus		cm³	Plastic Section Modulus	Section Modulus	Structural Engineer	0ZMi60qRqHu000041QrE$V	CircularHollowSection_Performance
Tortional Intertia Constant		cm⁴	Tortional Intertia Constant	Moment of Inertia	Structural Engineer	0ZMi60qRqHu000042QrE$V	CircularHollowSection_Performance
Tortional Modulus Constant		cm³	Tortional Modulus Constant	-	Structural Engineer	0ZMi60qRqHu000043QrE$V	CircularHollowSection_Performance
With		mm	Specified dimension of the shorter side of a rectangular hollow section. Specified outside dimension of an elliptical section on its minor axis	Length	Structural Engineer	0ZMi60qRqHu000044QrE$V	CircularHollowSection_Geometry
Height		mm	Specified dimension of the longer side of a rectangular hollow section. Specified outside dimension of an elliptical section on its minor axis	Length	Structural Engineer	0ZMi60qRqHu000045QrE$V	CircularHollowSection_Geometry


12x
Hexagon Socket
Head Cap Screw
ISO 4762 - M6 x 40
3x
Shear Box
Machined Steel.
BWM-7004-MFR-010.
6x
Maxifix E capped
connecting bolts
262.87.781

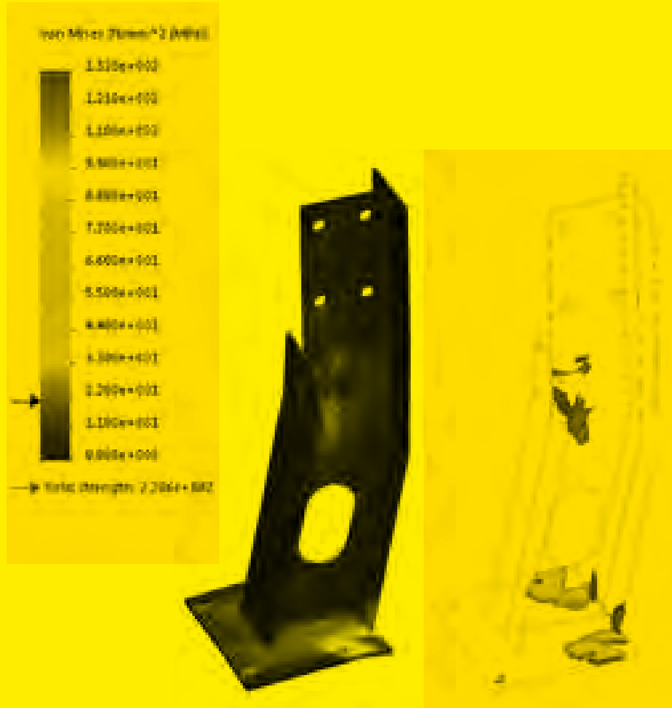
Beyond Uniclass – Material and new product data

Beyond Uniclass there are two other types of data which can be also be linked:

- Data that relates to the material properties of individual components
- Data that relates to products with new groups of components

Being able to link this detailed data to the rest of the Uniclass data extends the quality assurance process, enabling us to track, trace and test material performance in both existing and innovative forms.

Mechanical properties of individual components



PHYSICAL PROPERTIES OF STAINLESS STEELS

GRADES	DESIGNATIONS ( ) EN [N°]	AISI/ ASTM	DENSITY at 20°c [kg/dm³]	MODULUS OF ELASTICITY at 20°c [GPa]	MEAN COEFFICIENT OF THERMAL EXPANSION [$10^{-6}xK^{-1}$] 20°C÷200°C	20°C÷400°C	THERMAL CONDUCTIVITY at 20°c [W/(mxK)]	SPECIFIC HEAT at 20°c [J/(kgxK)]	ELECTRICAL RESISTIVITY at 20°c [(Ωxmm²)/m]
AUSTENITIC	1.4372[I]	201	7,8	200	15,7[a]	17,5[b]	15	500[e]	0,70
	1.4373[I]	202	7,8	200	17,5[f]	18,4[b]	15	503[d]	0,70
	1.4371[I]		7,8	200	17,5	18,5	15	500	0,70
	1.4597[I]		7,8	200	16,5	17,0	15	500	0,73
	1.4369[I]		7,9	190	17,0	18,5	15	500	0,70
	1.4310[I]	301	7,9	200	17,5	18,0	15	500	0,73
	1.4319[I]		7,9	200	16,5	17,5	15	500	0,73
	1.4318[I]	301LN (301L)	7,9	200	16,5	17,5	15	500	0,73
		302[h]	8,06	193	17,2[a]	17,8[b]	16,3[c]	503	0,72
	1.4305[I]	303	7,9	200	16,5	17,5	15	500	0,73
	1.4301[I]	304	7,9	200	16,5	17,5	15	500	0,73
	1.4311[I]	304LN	7,9	200	16,5	17,5	15	500	0,73
	1.4948[I]	304H	7,9	200	16,9	17,8	17	450	0,71
	1.4307[I]	304L	7,9	200	16,5	18,0	15	500	0,73

Uniclass classification – In delivery phase

The delivery phase is also included in Uniclass. The more efficient the design of platforms becomes, the greater the reliance will be on simple, efficient, repeatable assembly tasks that can also be classified.

Ss -	Systems
Ss_15_95	Temporary works systems
Ss_15_95_15	Temporary preparatory works systems
Ss_15_95_25	Temporary wall and barrier works systems

CA -	Construction aids
CA_20_10_20	Mobile working towers
CA_20_30_30	Guardrails
CA_20_30_30_35	Guardboards
CA_20_30_30_36	Handrails
CA_20_30_30_41	Intermediate guardrails
CA_20_30_30_89	Toe boards
CA_20_30_80	Work platforms
CA_20_30_80_01	Adjustable platforms

Classification of temporary works and construction aids

Configuration

Data and configuration

To standardise design through platforms, we need to digitise data in the form of a library that can take data beyond Building Information Modelling (BIM).

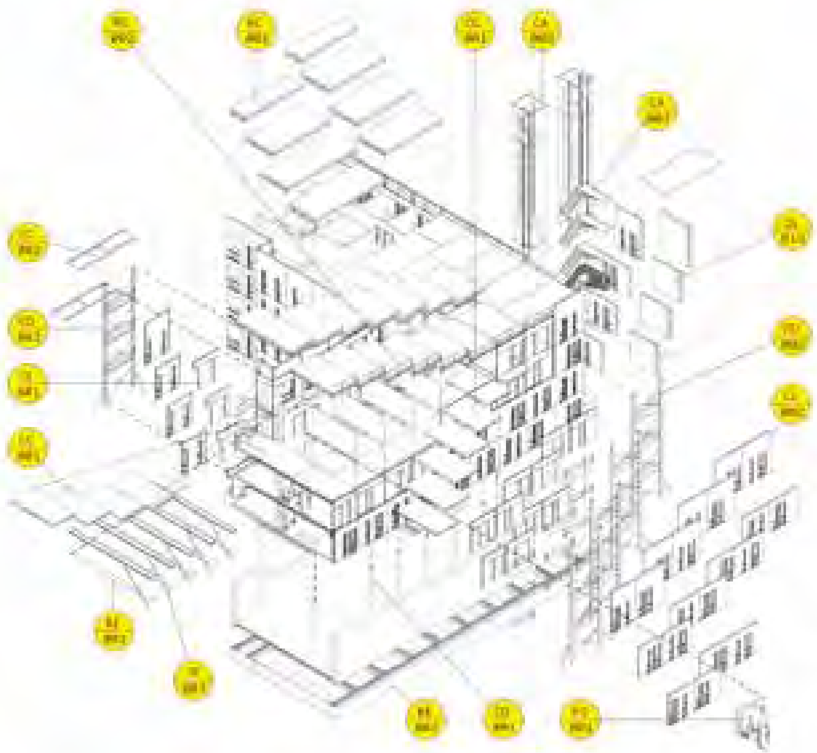
BIM is, fundamentally, a collaborative way of working that is powered by digital technology. By optimising the use of the existing governmental department BIM libraries, enhanced with components specific to the early platform developments, there will be a huge amount of cross-programme data available through site-specific models that can be uploaded to a digital library in the Common Data Environment (CDE).

> This mobilisation of data helps users make best use of the wealth of data available. No longer overwhelming, it becomes easy to manage and utilise.

These highly-detailed data libraries that aggregate multiple data sets

- Bring multiple sites into a single, project-wide view;
- Dramatically increase the level of transparency and control;
- Inform strategic planning and decision making;
- Give a level of insight that is rarely available to clients.

Healthcare project model and the digital library generated from it



Sample data visualisations showing precise counts of components and their installation periods, derived directly from the model.

Critical to the usability of this data is the visualisation of it.

Data visualisation techniques work at a variety of scales, so certain techniques allow whole-project analysis, while others allow the optimisation of individual components or assembly processes.

The visualsation of data means that all members of the project can use it for

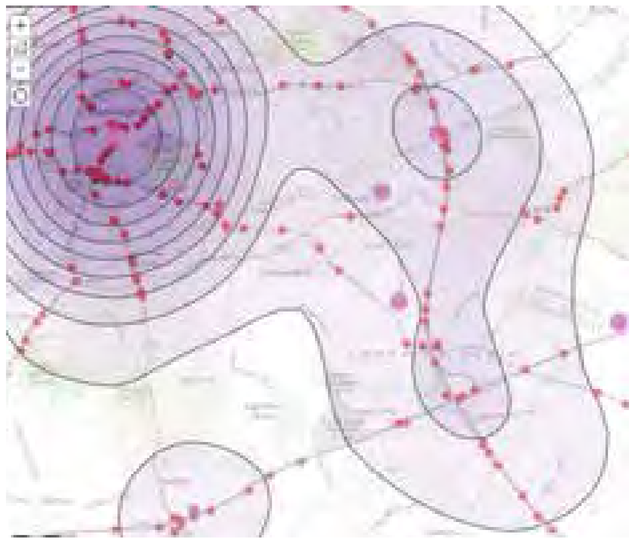
- Colour filtering of models to create heat maps showing the intensity of trade overlap, cost per hour of installation etc.;
- Allowing multiple stakeholder views to be combined, addressed and prioritised;
- Making legible the interdependency between a range of factors that impact productivity;
- Providing a single point of entry to a wide range of digital content.

The benefits are broad. For instance: visualising interaction between various work faces so that knock-on effects of delays in one area can be better understood facilitates

- A more holistic view of project-wide progress;
- Strategic prioritisation and optimisation of work faces/packages;
- Smoothing of cashflow or labour;
- Smoothing demand for individual components through just-in-time delivery, reducing stress on the supply chain, enhancing their productivity and therefore lowering price;
- Optimisation of resources by understanding how operatives and plant can be shared.

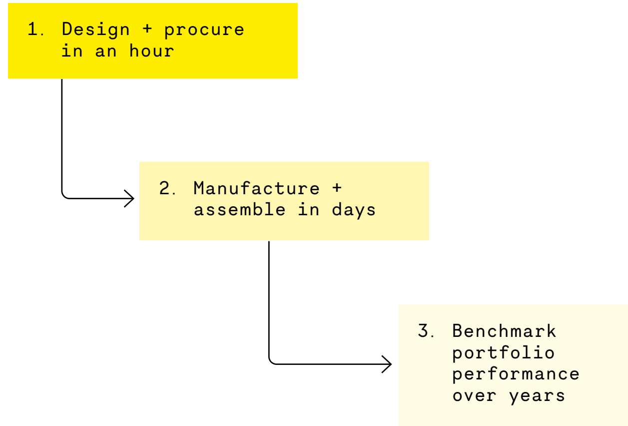
Heat-map analysis

Contour analysis



To move to standardised, highly productive, manufactured solutions, this data also needs to flow seamlessly across the process of design, procurement, manufacture and assembly. Plus, if resulting assets are to be smart, then we need to ensure that data continues to flow, so that operational and performance learnings can inform future assets, projects and portfolios.

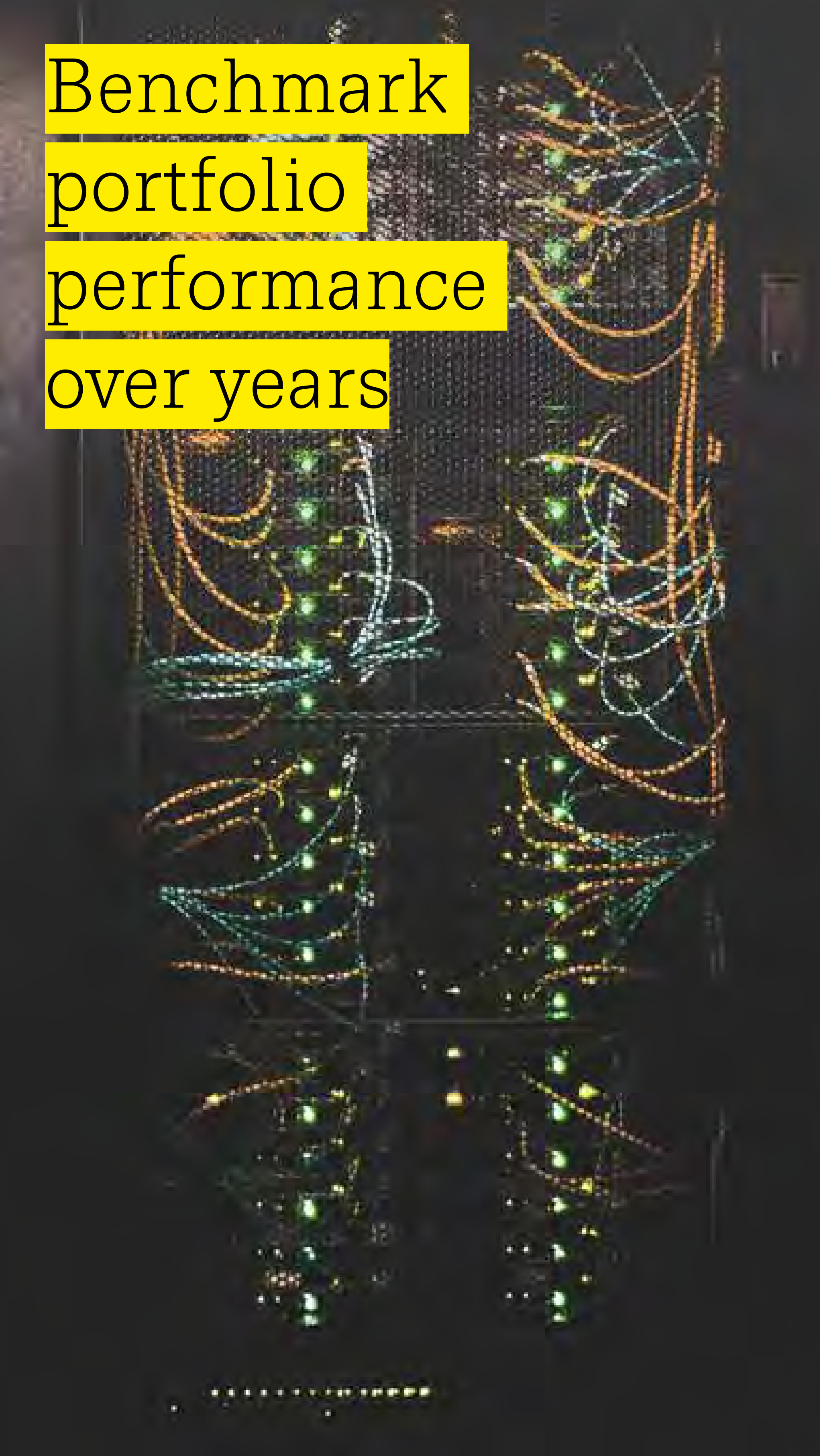
Digital configurators will ensure this seamless flow of data and speed up the entire process. Imagine the impact of this three-step process:



Design and procure in an hour

Manufacture and assemble in days

Benchmark portfolio performance over years



Step 1: Design and procure in an hour

Digital configurator

A digital configurator is a database of standard components and elements, with customisable options specific to the building type.

The intelligent algorithm within the configurator will offer the relevant options consistent with the building type.

For example, choosing ‘school’ will limit the room types – the spaces – to those relevant to a school.

The boundary wall, window and door options for a school classroom differ from those for a high-security prison.

The algorithm will allow the building to be configured based on the size (number of pupils, patients, workers, prisoners etc.) and the footprint (linear, T-shaped etc.), and will include ancillary facilities (staff rooms, canteens etc.) relevant to the building type.

Virtual marketplace

The virtual marketplace is the key customer interface in which the digital configurator sits.

The digital configurator is embedded in a virtual marketplace and from the algorithm can produce the basic design pre-options, together with a nominal ‘base price’.

Within the marketplace, where relevant, the client could then add their options. They can choose the external cladding type based on a number of architectural options, the floor and wall finishes etc. All of these options, much like a BMW configurator, would show how they add to the base price.

When configuration is complete, the client can click ‘add to basket’ and then shop for more, or proceed to checkout.

Checkout

Checking out launches the procurement process. At this stage, the client knows his ‘should cost’ for his scheme with options. How the market can and will supply this depends on their operational model.

At a simple level, the options could range from ‘manufacture and assemble’, to ‘finance, manufacture, assemble and operate’.

The marketplace – of approved suppliers and products – then offers to provide the service requested.

The agreed supplier then moves to Step 2.

BMW allow prospective customers to specify a number of options – colours, trim, engine options etc. based on a range of standard model chassis.

Volkswagen Group's platform sharing architecture

Ikea use a similar tool for their kitchens with a range of user-customisable options (worktops, appliances, doors, handles) based on standard mass-manufactured frames that are scalable to suit kitchen size and layout.

Step 2: Manufacture and assemble in days

With the scope determined and the procurement route chosen and the supplier selected, the digital configurator will electronically generate the component lists which will be fed to the factory facilities for production.

In parallel, traditional site preparation can commence – earthworks, foundations etc. – so the site is ready to receive the components.

In addition to the manufactured components, connections, building services etc. required for the structure, the configurator can generate the plant and equipment needed for assembly and temporary site logistics – messing, offices etc. – again drawn from standard, reusable units appropriate to the location and scale of the facility.

Step 3: Benchmark portfolio performance over years

Data will be collected from in-service performance to ensure outputs and outcomes are delivered across the estate.

Data can inform strategic interventions for maintenance and operational effectiveness, and be used to ensure appropriate strategic spares are held to service the needs of the estate.

Output from the data and benchmarking will be used to refine and optimise the designs and methodologies and to inform decisions taken at the front end of new projects.

Manufacture

Prototyping

Prototyping

Analysis and experience to date suggest that many major programmes could be delivered using a limited number of relatively simple components, developed in such a way that they can be procured at low cost but consistent quality from a wide supply chain.

Once the repeatable elements have been identified and described, the BIM library objects can be used collaboratively by the project team to establish an installation sequence that is much more similar to factory assembly than traditional construction, creating the potential for

- Standardising working;
- Capturing and incrementally improving upon of best-in-class methodologies;
- Using a nontraditional workforce specifically trained in installing the proposed solution.

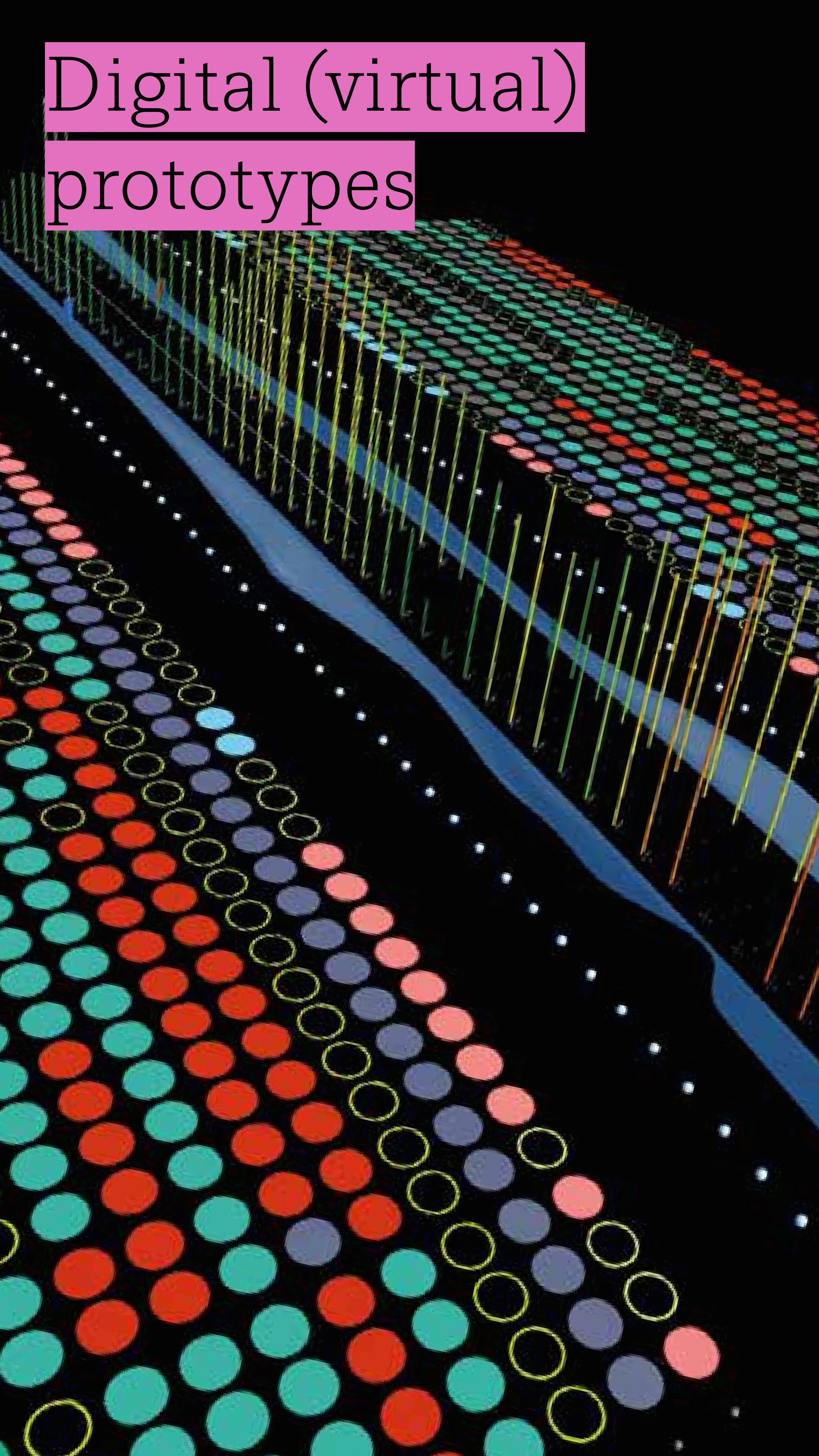
For certain critical and highly repeated elements, the benefits of refining and perfecting them are enormous: any improvements that are made as a result of this process will be multiplied across the programme. Any issues that arise through failure to prototype will conversely appear numerous times.

In the development of industrialised products, the purpose of a prototype is

- Testing and trialling a new design;
- Testing and optimising installation or construction sequences;
- Identifying any opportunities to refine and improve the proposed design, installation etc. before commencing large-scale manufacture.

The ultimate aim is risk reduction by learning as much as possible from the prototype in a controlled environment, off the project critical path, to inform the development of the production run of the system or element.

There are three levels of prototype, which provide differing levels of feedback and learning but have commensurate levels of time and cost associated with them, including:


Digital (virtual) prototypes


Physical prototypes

Manufacturing process prototypes

Digital (virtual) prototypes

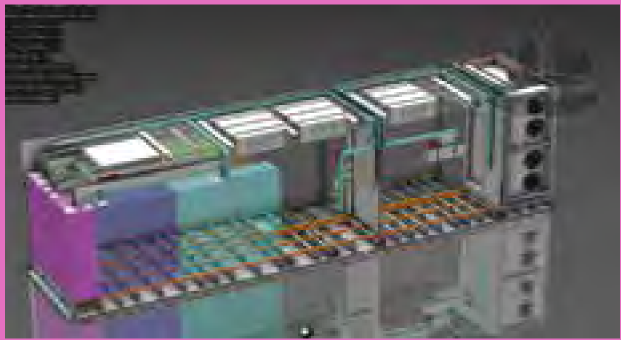
These are developed in sophisticated software packages that allow a wide range of analysis to be carried out without ever producing a physical element. Product-design software allows the digital components to have 'real' properties (such as density) to allow analysis, including

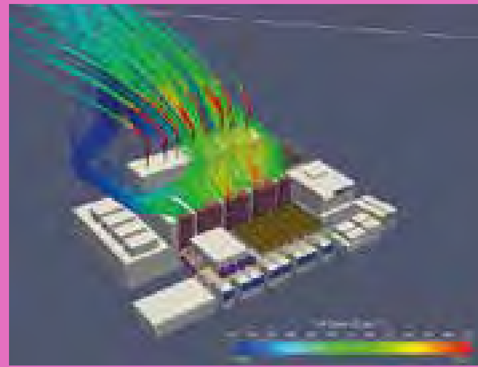
- Mass and centre of gravity (e.g. for craneage studies);
- Failure modes and effects analysis;
- Computational fluid dynamics.

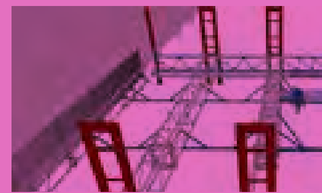
The result is an holistic virtual build that can be iteratively used to refine the solution by

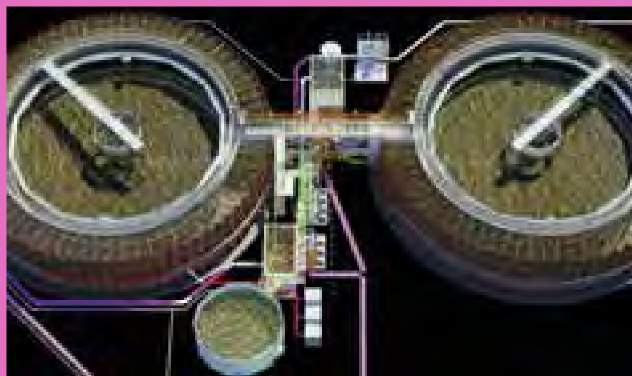
- Developing a model of a sample section of the initial industrial-design concept;
- Developing the model to include construction sequence, program, supply chain and resulting cost modelling;
- Filtering the model to determine quantities, program, site-labour histograms etc.;
- Assessing the outcomes of the virtual build against local benchmark norms for cost and against aesthetic and quality issues;
- Considering modifications to the components on the component deployment and assembly techniques in response.

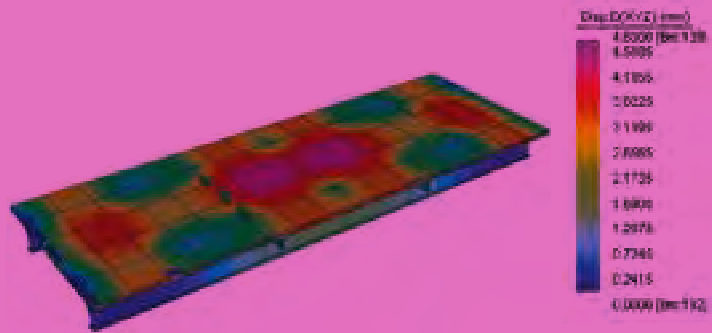
Virtual prototypes across a range of sectors

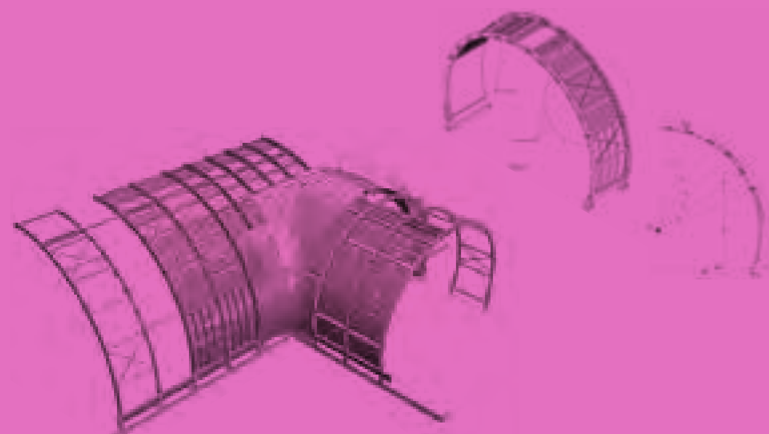












Physical prototypes

This is a full or partial section of an element or assembly, usually at full scale and using the final proposed materials, which can be used to test the physical characteristics of an element or system, including installation. Physical prototypes are typically created for learning purposes only, not for deploying in a live environment. Significant issues may be identified in the creation of a prototype.

The benefits of creating physical prototypes are particularly high for the transformation rollout project. Before embarking on a process of building eight thousand prisoner spaces, a relatively small prototype could be used to

- Demonstrate the delivery system in practice;
- Optimise the assembly sequence and create installation / health and safety guides;
- Provide detailed data regarding assembly to inform construction programmes, logistics planning etc. with a relatively high degree of certainty (compared to prior efforts which are necessarily based on assumptions);
- Provide training for assembly crews, crane operatives etc.

The benefits will include

- Better, more targeted engagement of suppliers, as the required end product will be extremely well understood and defined;
- More objective assessment of suppliers, as the quality of their products can be measured against a known standard;
- Greater consistency across the two buildings – labour teams will be able to work on any plot, as the methods of construction will be identical;
- Assembly teams able to be trained using the prototype before going on site, so productivity on site will be high from day one (no learning curve on actual buildings);
- Greater opportunity for measuring progress on site, creating feedback loops and driving continual improvement.

Physical prototypes across a range of sectors

Physical prototypes across a range of sectors

Manufacturing process prototypes

Manufacturing process prototypes are well established in other industries such as aerospace, manufacturing and defence. Those sectors rely on virtual prototypes to verify and validate processes prior to the physical commission of the equipment.

The virtual process prototype allows:

- Rapid testing of different manufacturing sequences under a full-scale production scenario
- Optimum utilisation of resources, material and equipment
- Elimination of physical collisions with structure
- Identification and mitigation of potential process-capability issues (i.e. time, cost and quality)
- Reduction of installation and commissioning time
- Validation of robotic paths and programmable logic-controller programs
- Identification and mitigation of ergonomic and health and safety issues
- Quicker natural interpretation for better-informed decisions
- Replacement of expensive full-scale prototypes
- Operator training
- Optimisation of design for manufacture and assembly
- Identification of bespoke tooling, jigs and fixtures

Companies in those industries have benefited from using virtual prototypes to optimise their manufacturing processes before the physical installation and achieving, in some cases, significant figures:

- Reduction of 25% on annual operational costs
- Reduction of 80% on capital equipment
- Increase utilisation of resources by 20%
- De-risked strategy through simulation techniques
- Part count reduced by 30%
- Assembly cycle time reduced by 27%
- Variable volume and product assembly process
- Reduced facility commissioning time

Virtual 'process prototype' in the immersive Cave Automatic Virtual Environment (CAVE) at MTC, Coventry.

Virtual prototype: production line.

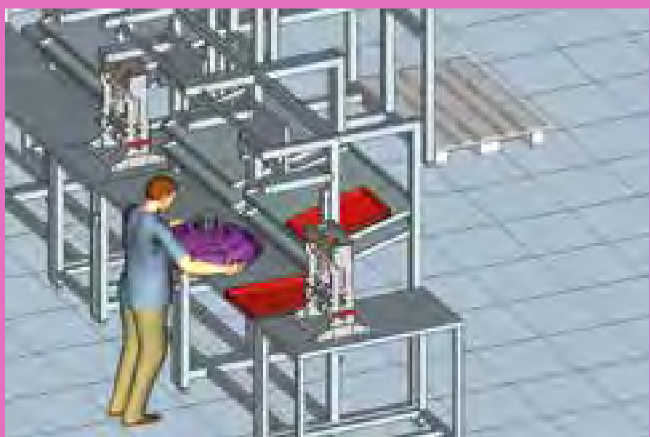
After the process-prototyping validation exercise, manufacturers will also run pilot processes, running a small-scale production line to produce physical components to test and trial production within a controlled environment. This will help them to optimise the future manufacturing process and

- Identify potential capability issues and mitigate them prior to escalating to full production;
- Test and debug different line configurations without having to disrupt other production areas;
- Optimise the manufacturing line prior to full-scale production.

Virtual prototype: testing production-line configuration.

View inside the MTC CAVE.

Virtual prototype: laser welding cell.



Process simulation.

Virtual prototype: assessing worker's visibility.

Engineering review of a component using Virtual Reality.

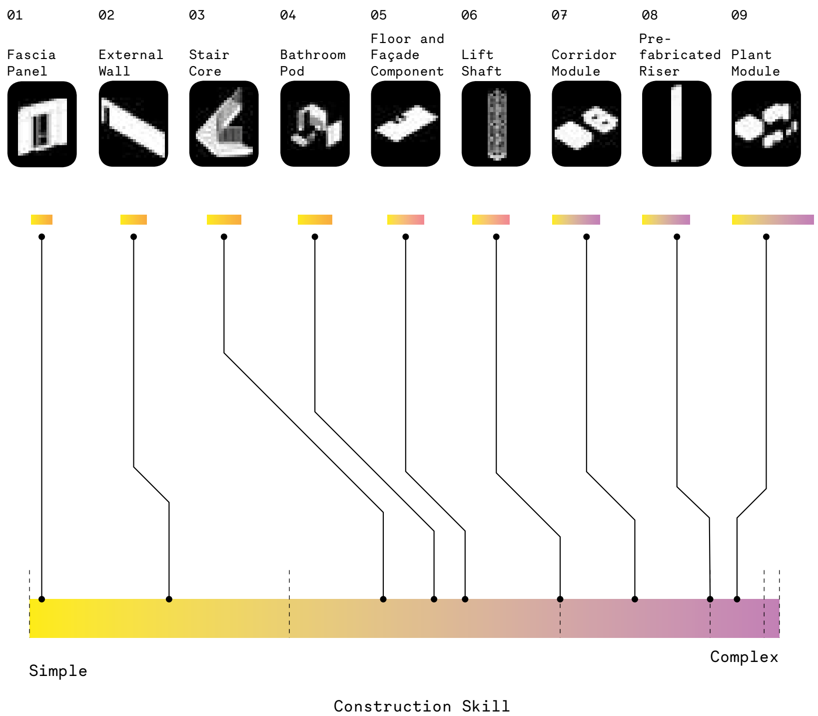
Supply Chain Mapping

Supply chain mapping

The use of an industrialised manufacturing approach allows the supply chain to be treated very differently than in traditional construction.

The diagram below is a typical output of an assessment of the components required to create a rollout programme. This assessment could be developed specifically for the transformation project at the assembly stage (as part of the standardisation and optimisation exercise). In particular, the ability to develop components using low-skilled labour could facilitate the use of prisoner population manufacturing capability, or employing the workforce in Scotland that traditionally works in the oil and gas sector.

Component assessment: Potential to use low-skilled operatives



Manufactured products are often made many thousands of miles away from their point of use; value is created where operatives are low cost and abundant. This is further enhanced by ensuring that manufactured products can be assembled by low-skilled personnel, making the supply chain as wide (and therefore as competitive) as possible; this may extend to non-construction companies.

Once the design analysis is complete, it will be necessary to start identifying supply chain partners for the delivery of the scheme. This assessment may be far-ranging and will consider components in terms of three criteria:

- Size
- Weight
- Complexity

The design of the repeatable elements can then be refined in line with supply chain capability and capacity.

By working with and designing towards a supply chain, the benefits of their existing skills can be optimised, with benefits to cost and quality.

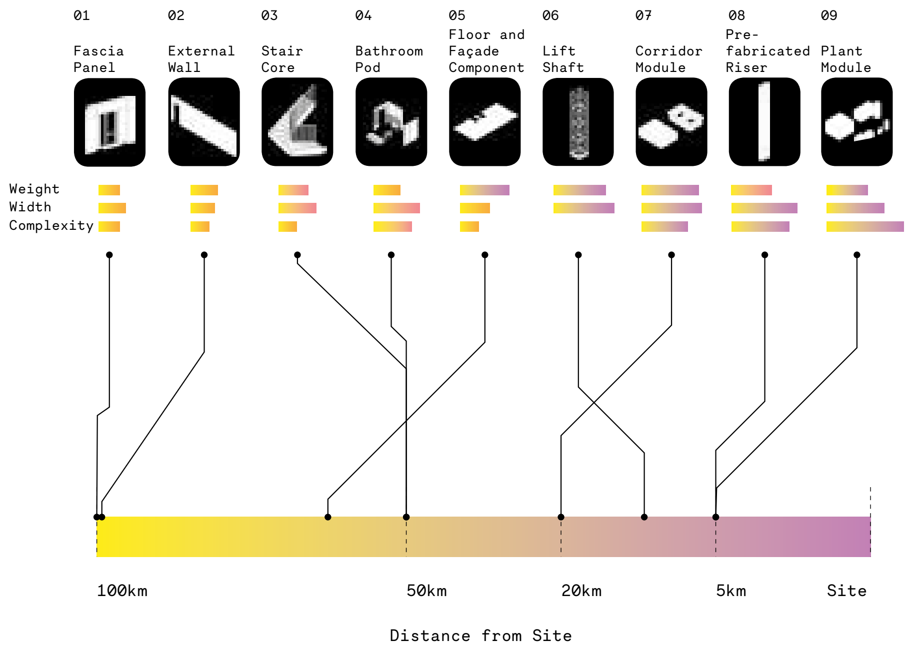
Outcomes should include

- Extremely wide, and therefore resilient, supply chain for all major components with good regional coverage for all sites to maintain commercial advantage while minimising transport and logistics costs;
- Ability to utilise a number of small companies rather than rely on large single-source suppliers;
- Ability to manufacture complex components where specialised skills exist, but use local labour for final on-site assembly.

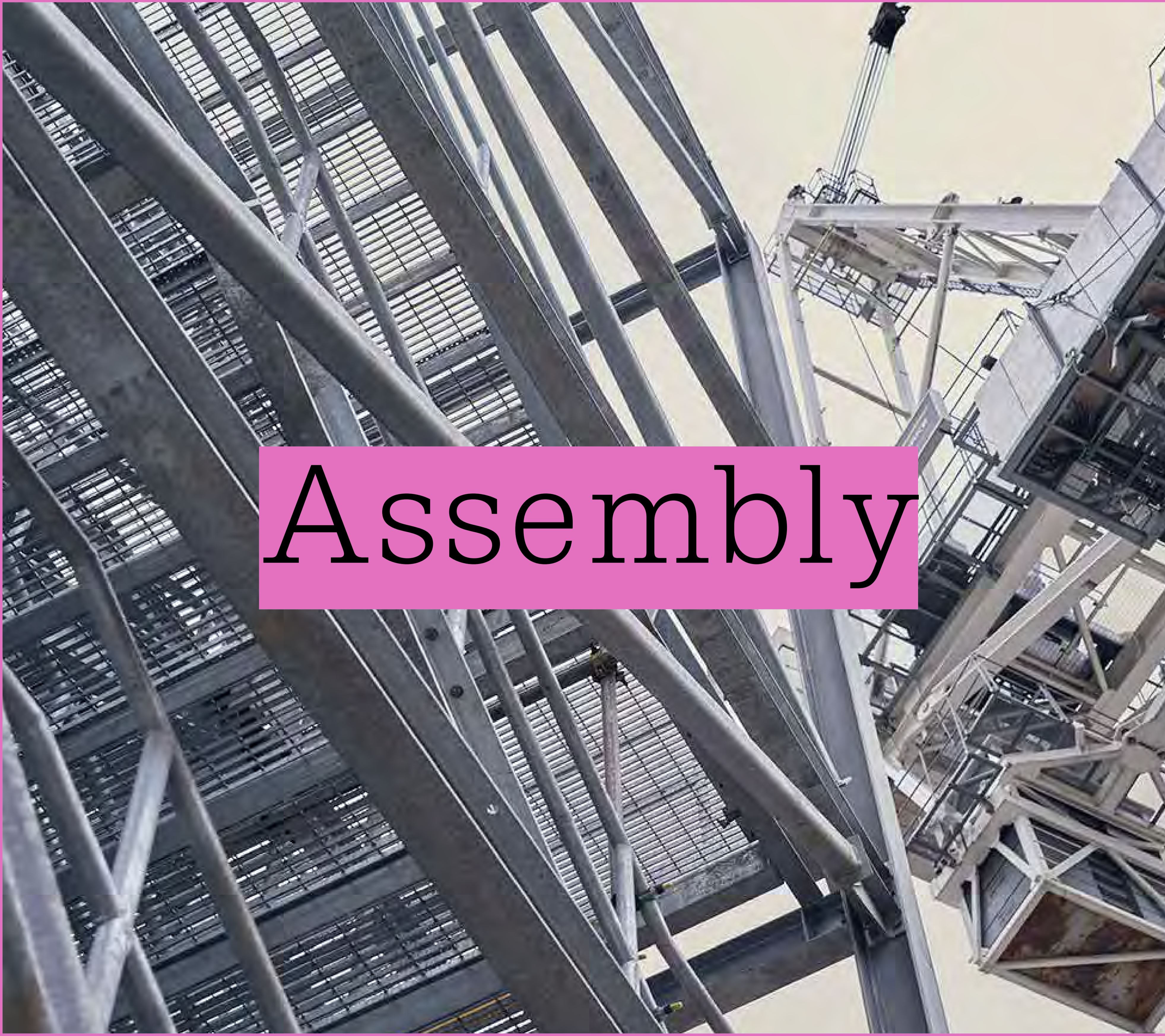
By working with supply chain partners, where appropriate, the components can be developed to a fit-for-fabrication or manufacture stage. With input from the MTC to drive enhanced manufacture processes, benefits could include:

- Trade contractor drawings virtually eliminated, as where possible all coordination takes place using aggregated models
- Clashes detected and resolved within the digital environment well before fabrication commences
- All interfaces fully resolved digitally
- Fabrication models used for the 'virtual building' exercises described later in this document
- Impacts of proposed changes assessed using updated models to provide clearly understood and objective metrics
- 'As built' models readily assembled from the fabrication models
- The aggregated models ready to be populated with operations and maintenance / facilities management data

Component assessment, potential to create value remotely from site



Assembly



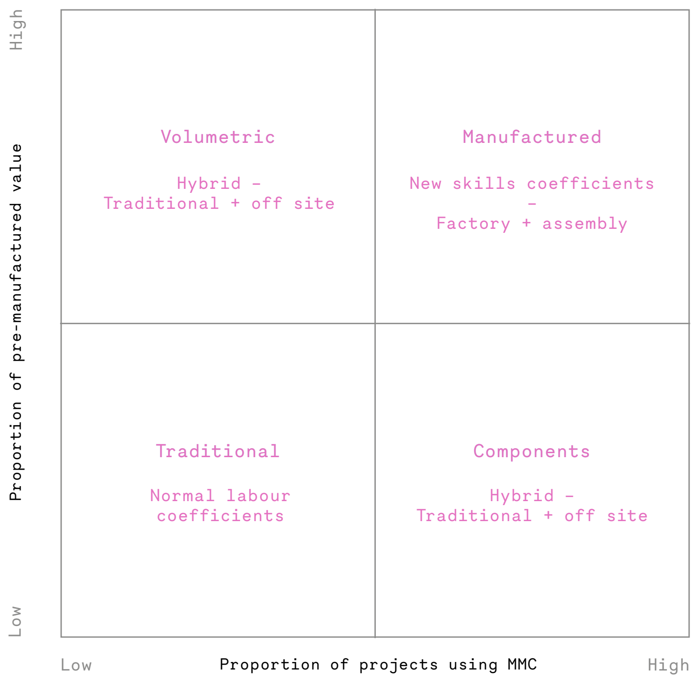
Training

Adopting a platform approach will necessitate a significant growth in manufacturing skills, requiring new apprenticeships and training regimes.

Different skills are required for the different proportions of MMC.

While componentised and volumetric solutions require a hybrid of traditional and off-site skills, a manufactured solution will require factory-based and assembly skills, plus better logistics planning etc.

Developing new skills for manufactured solutions

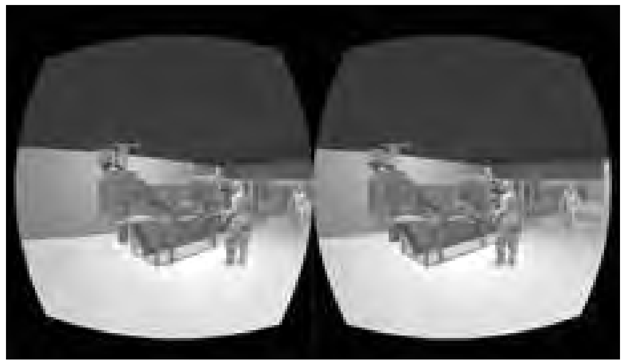


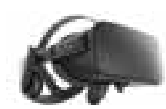
To ensure high productivity and safety on site, we will need advanced construction training, using all the available technology for the training of operatives.

Virtual prototypes can be used to train operatives in the assembly of components, subassemblies and entire projects in a very safe and low-cost environment before they are allowed to enter the relatively higher-risk live environment of a site. Installation sequences can be tested and optimised so that time on site is not spent working out problems.

There are a range of tools and outputs to do this, including:

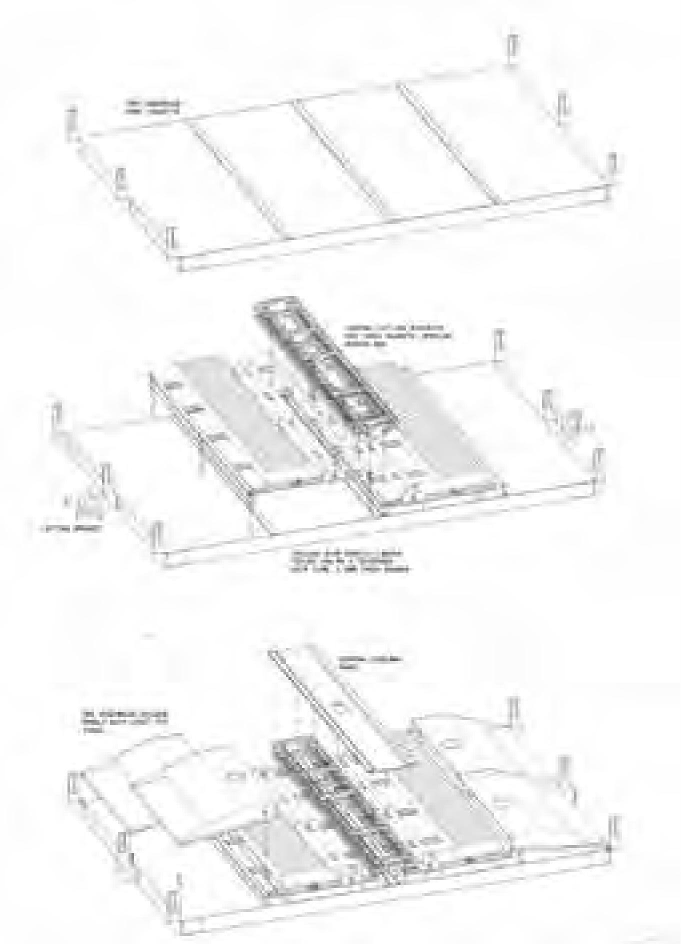
- Ikea-style diagrams
- Animations
- Training guides
- Immersive / virtual reality training programmes
- Daily 'tool box talks' using the BIM models ahead of an on-site work shift to talk operatives through the work ahead, point out particular health and safety issues and ensure everyone is clear on the tasks
- Visual method statements accessed via QR codes attached to the physical components at point of work





Oculus Rift headset used for virtual induction.

Extract from an assembly training guide



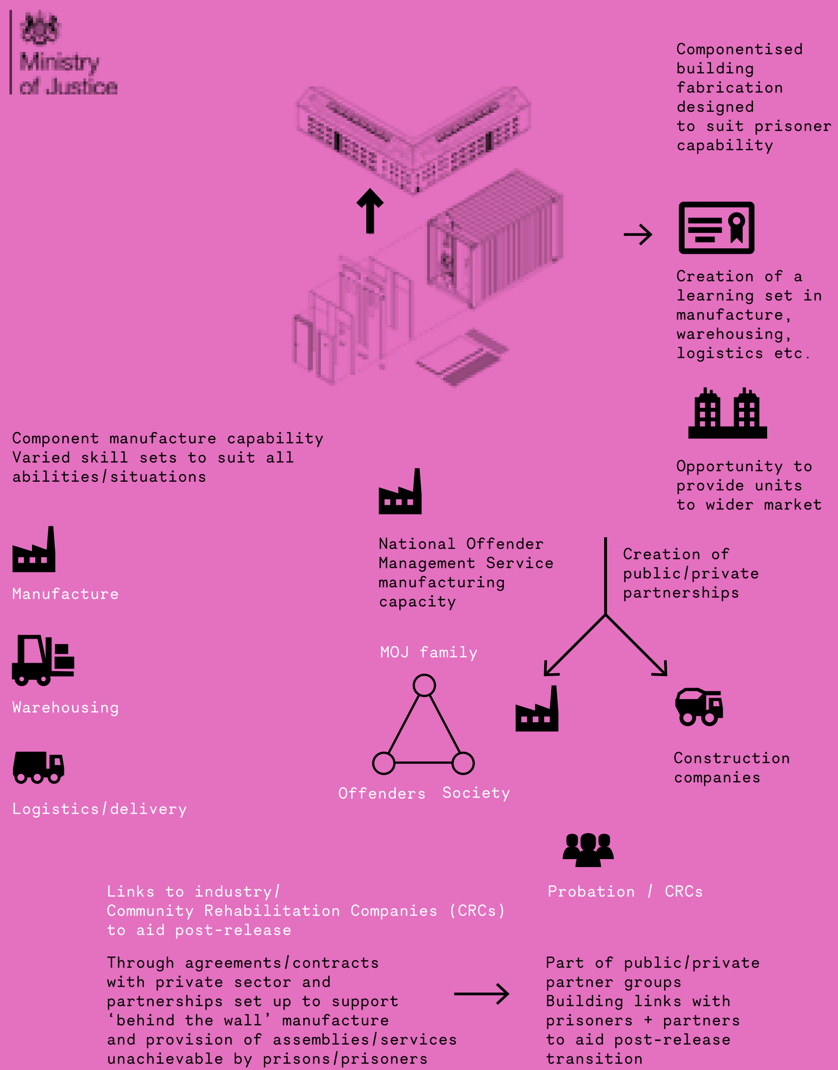
By ensuring that the correct information is available directly when required, there will be significant benefits in terms of operative safety and productivity.

The use of a platform approach increases the productivity of operatives. But importantly, it also allows the supply chain to create value where operatives are low cost and abundant, ensuring manufactured products can be assembled by low-skilled operatives to deliver high-quality buildings.

This could certainly facilitate the use of apprentices as described in HM Treasury's report 'Fixing the Foundations'.

This approach could also make use of lower-skilled, local labour on individual sites, to carry out standardised tasks alongside more skilled operatives.

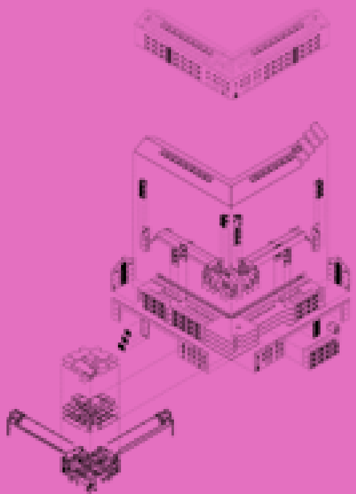
Major programmes in particular offer the potential for using existing or enhanced manufacturing capability within the prisoner population, for example; the delivery system could be designed to use simple but highly repeated components that could be made by very low-skilled operatives.



A comparison of a costed solution for a 180-person house block delivered using the platform design against benchmark data for a range of traditionally delivered schemes demonstrated

- A cost reduction of 17% to 22% if delivered using external supply chain;
- A cost reduction of 30% to 32% when prisoner population labour was factored in;
- A programme saving of 30% for the first prison;
- Programme savings of 50% once the installation of the repeatable elements was practised, optimised and standardised.

While this was a major improvement, the greatest benefit was in the impact on re-offending rates; in using prisoner-population labour, the proposal was to provide inmates with a range of accredited skills in manufacturing, logistics and warehousing that could be used upon release. This would reduce re-offending and probation costs, while also addressing the skills shortage in construction and supporting the growing market for off-site construction. The same workforce could also be deployed in the delivery of other public sector needs, e.g. schools and hospitals.



Industrial Modular Accommodation Concept

Traditional accommodation

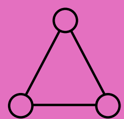
• Cost	£5,500/m^2
• Programme	13 months
• Prisoner regime	Very low
• Supports reduction of re-offending	No

New componentised 'prisoner centric' accommodation

• Initial Cost	£4,270/m^2
• Target cost once industrialised	£3,720/m^2
• Initial programme	9 months
• Target programme once industrialised	6 months
• Prisoner regime	Very high
• Supports reduction of re-offending	Yes

How?

MoJ family

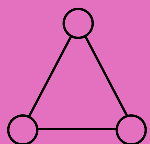


Offenders Society

Corporate Services: Estate Directorate

MoJ family

- Manage population pressures
- Reduce financial pressure
- Create regime activity
- Increase use of industrial facilities



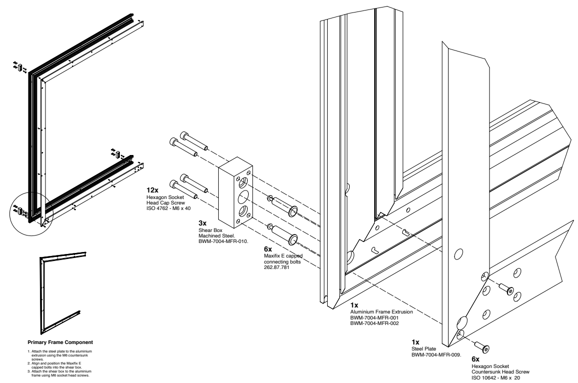
Offenders

- Time spent usefully
- Accredited skills
- Build links for release

Society

- Emerging 'off site' construction market
- Growing commercial awareness for corporate responsibility
- New probation CRC 'payment by result' initiative

For the Heathrow and Gatwick Pier segregation modules, the initial projects were assembled using traditional site-based personnel, relocated to a factory. However, as the installation sequences became optimised and better documented, we were able to take unemployed people with no previous experience and train them to assemble these modules. The result for the client was a labour cost that was reduced by 75%.



Structural system – training manual.

Virtual Induction

These training programmes can be extended beyond construction operatives (how to build a facility) to staff (how to work in and operate the facility).
For example, for GSK, Bryden Wood has developed a virtual induction: operatives 'walk' through the model, select appropriate personal protective equipment (PPE) and answer questions on safety before they can enter their 'work area'.

Screen grab from training video.

GSK 'Factory in a Box'

For the GSK 'Factory in a Box', Bryden Wood has successfully used non-construction operatives (ex-Army servicemen) to deliver the project. During the assembly process, 17% of the operational hours were expended on briefing, training etc., but the project was delivered with a 60% programme saving and a 75% reduction in workforce.

Component colour coding and QR coding.

Mission Control

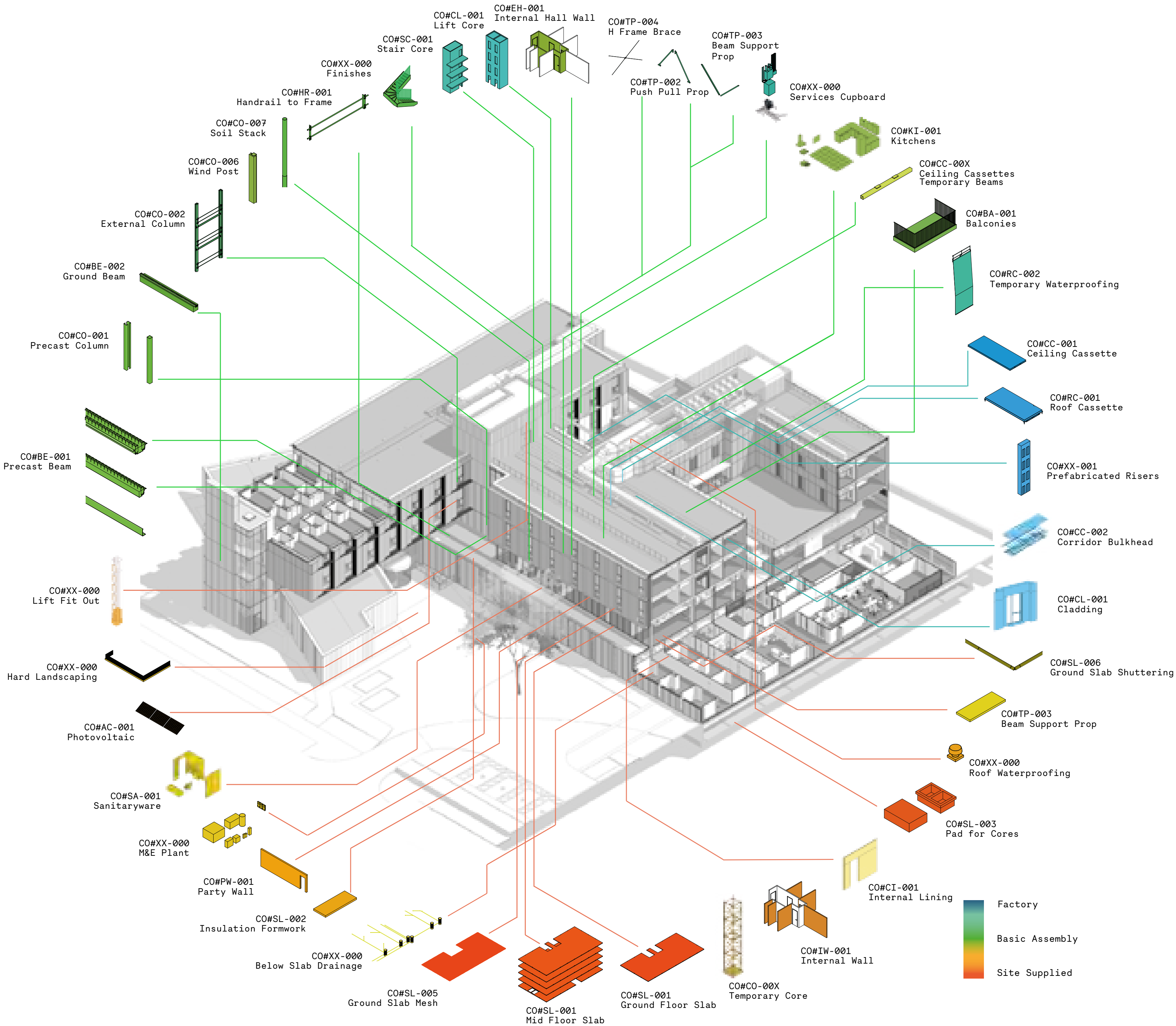
As the design and procurement of platforms becomes increasingly efficient, if logistics and assembly are disorganised on site, the benefits gathered could easily evaporate.

The interaction of the platform components with other systems will become critical in order to drive the efficiency right through the construction process, ensuring that high productivity and full benefits are leveraged.

As a result, site installation must be well planned and managed. To achieve this, we can use the digital library and model to optimise and rehearse the site-assembly sequence. The advanced use of BIM generates highly accurate (in some cases fabrication quality) representations (i.e. models) of the final building.

These models can then be used for 'virtual build exercises', which will optimise assembly sequence, test health and safety aspects and create highly detailed assembly manuals and installation programmes.

Detailed construction and logistics planning model



To generate the required level of accuracy, we will need to input the following groups of information:

Activities

Includes install time and duration as attributes in the models to enable

- Linking the programme to the model so that the build sequence can be shown in a clear visual manner
- Testing construction sequences and scenarios
- Assessing and improving health and safety impacts

Interface and collaborate with tier delivery partners regarding

- Planning logistics (placement of cranes and hoists, delivery of materials versus programme etc.)
- Planning and optimising temporary works
- Progress reporting from site, planned versus actual progress, time slice reports etc.

Outcome – Pre-construction

- Programme and construction sequence tested virtually to create optimised programme
- Critical path identified and protected
- Logistics plans tested for difficult parts of the programme
- Health and safety reviews carried out for complicated build sequences
- Temporary works erection and removal tested against permanent works

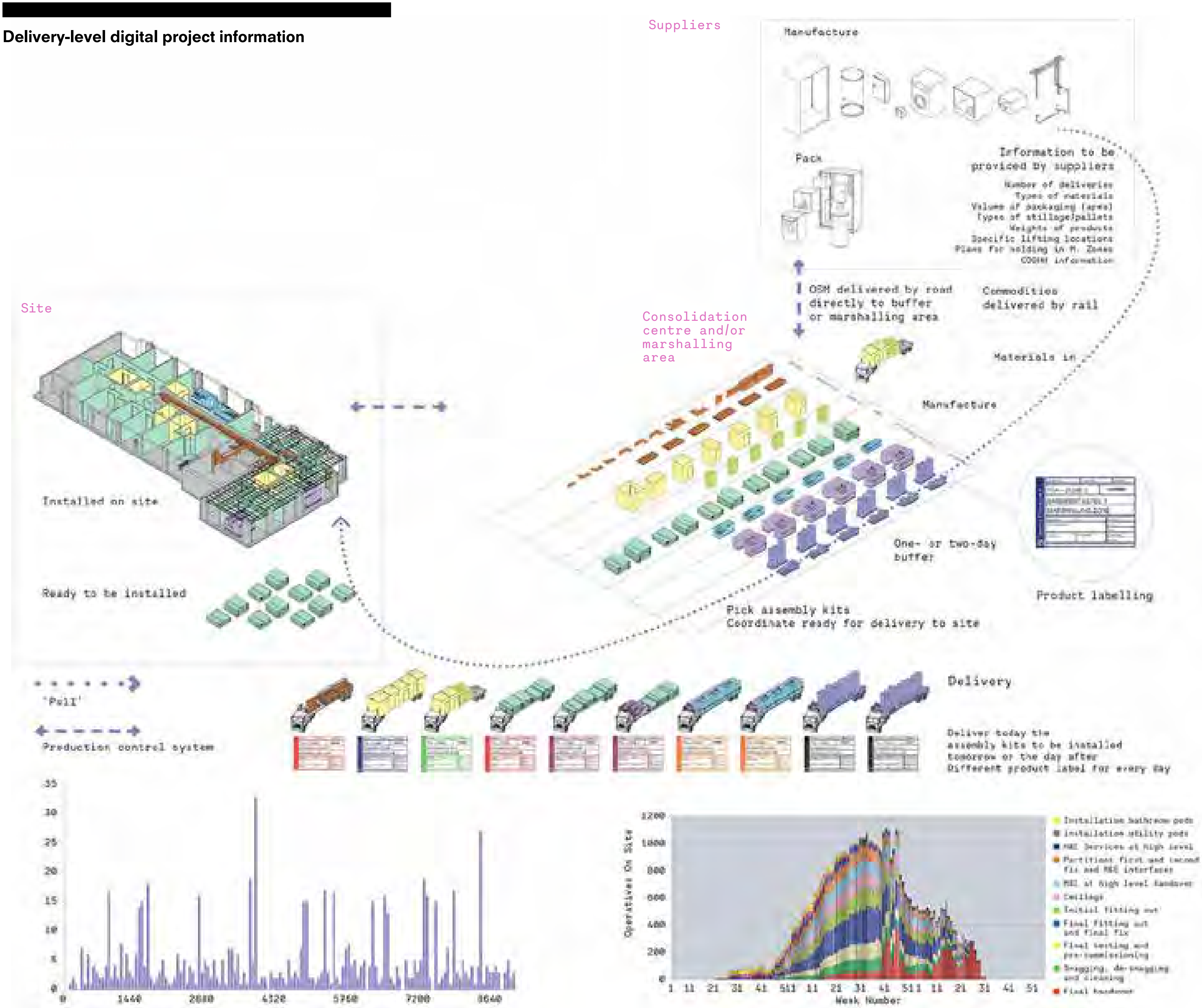
Outcome – Construction phase

- Construction status fed back to the models for visual reporting
- Feedback loops in place to identify activities preventing timely delivery
- Accurate reporting and mitigation strategies for Early Warning Notices etc.
- Accurate forecasting for impacts of change

Outcome – Handover

- Plan commissioning activities, based on which systems are interlinked and must be tested in a particular sequence etc.
- Optimise handover schedule
- Review phased handover scenarios – testing which areas can be made fully functioning and safe for the client to commence fit out or occupation

Delivery-level digital project information



The use of standardised solutions, supported by digital libraries and models at the scale and geographic diversity of the government estate, combined with open and collaborative ways of working, offers the chance to create an exemplar project-control system for the BIM-enabled industry. This project control system would comprise two aspects:

- Mission control
- Connective role

Mission control

By combining all of the available data sets, bridging the traditional boundaries (physical and imagined) between ‘the site’ and ‘the factory’, a combined, single data flow would link manufacturing centres to the construction zone.

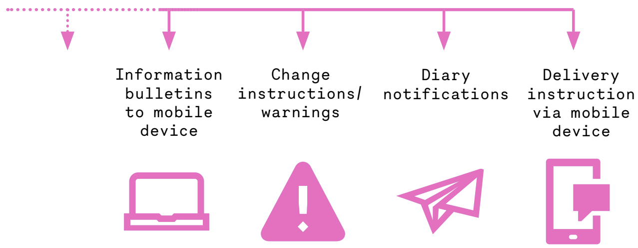
This data would be assimilated in one virtual space, although it is likely that this would also become a physical space, where all team members could gather and use the digital infrastructure together or individually.

This mission control space would be a living project-management space; a responsive, learning space, which can efficiently help deploy key data to manage the delivery of the project efficiently.

This would be used for more agile and responsive project control, linking suppliers, logistics and sites in a highly organised network, supporting:

- Higher productivity
- Better levelling of supplier workload
- Just-in-time delivery
- Fewer on-site movements
- Reduced waste

Mission control: A physical and/or digital space



Mission control's high-quality and accurate data would be received from a range of existing sources including:

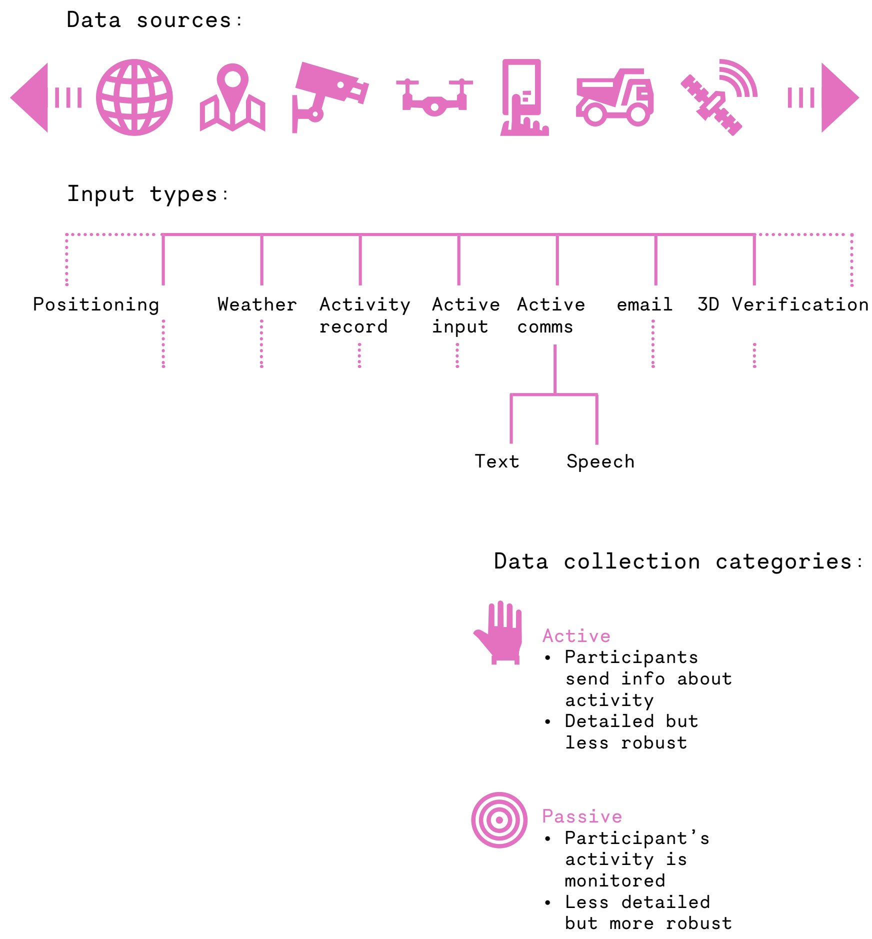
- Operatives – activity recording using GPS-enabled smartphones with custom apps;
- Vehicles – GPS tracking for all construction vehicles, recording all delivery journeys as well as on-site activity
- Mesh-network-enabled CCTV monitoring systems using balloons
- Drone technology for image and video capture
- Digital weather stations / sensors monitoring air and ground conditions
- Photogrammetry / laser scanning for site topography
- Live traffic reporting
- Weather satellite data and services

Mission control will use the data capture and analysis to provide targeted communications to the project team and operatives across the site including:

- Better project planning prior to construction through detailed scenario studies
- Data-rich, visual feedback to assist project-planning decision making
- Accurate benchmarking of carbon footprint before construction, and use of this data as a driver for project planning
- Simulation of unusual/extreme events, and their potential impacts and possible mitigation
- Familiarisation of the monitoring system that will be used during construction
- Long-range forecasts for factory production with long lead time
- Weekly plans with detailed activity schedules
- Daily updates to site operatives for optimum deployment of workforce
- Hourly updates with weather warnings
- Real-time redirection of deliveries to avoid traffic or to hold points, in order to ease congestion at site entrances

The connective role

A new project role will also be required. This connective role will run mission control and the digital infrastructure housed within. This will be a digitally enabled role that will manage all data on live projects, ensuring efficiencies are held onto throughout the delivery and assembly stages of the project.



Dossier

Dossier

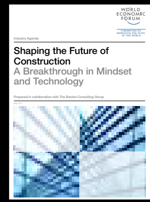
Recent publications containing supporting evidence and advocating the adoption of a platform DfMA approach

Infrastructure Client Group, *From Transactions to Enterprises: A new approach to delivering high performing infrastructure* (London: Institution of Civil Engineers, 2017).

Britain needs high-performing infrastructure, yet the model we use to deliver and operate much of our infrastructure is broken.

Features of a new approach include:

1. Governance
   - Owner's definition of value
   - Long-term relationships with suppliers
   - Performance measurement
2. Organisation
   - Coalition of suppliers
   - Aligned commercial interests
   - Effective organisation
3. Integration
   - Effective teamwork
   - Production management
   - Health, safety and wellbeing
4. Capable Owner
5. Digital Transformation



World Economic Forum and the Boston Consulting Group, *Shaping the Future of Construction: A Breakthrough in Mindset and Technology* (Cologny, CH: World Economic Forum, 2016).

Future best practice includes:

- Standardised, modularised and prefabricated components
- Digital technologies and big data along the value chain
- Front-loaded and cost-conscious design and project planning
- Strategic workforce planning, smart hiring, enhanced retention
- Mutual consent on standards across the industry
- Cross-industry collaboration along the value chain
- Actively managed and staged project pipelines with reliable funding

McKinsey Global Institute, *Reinventing Construction: A Route to Higher Productivity* (New York: McKinsey & Company, 2017).

- Construction-related spending accounts for 13% of the world's GDP, but the sector's annual productivity growth has only increased 1% over the past 20 years.
- $1.6 trillion of additional value added could be created through higher productivity, meeting half the world's infrastructure need.
- 5-10x productivity boost possible for some parts of the industry by moving to a manufacturing-style system.

Action in seven areas can boost sector productivity by 50-60%:

- Reshape regulation
- Rewire contracts
- Rethink design
- Improve procurement and supply chain
- Improve on-site execution
- Infuse technology and innovation
- Re-skill workers

McKinsey Productivity Sciences Center, *The construction productivity imperative* (New York: McKinsey & Company, 2015).

- 98% of mega projects suffer cost overruns of more than 30%.
- The average cost increase is 80% of original value.
- 77% are at least 40% late.
- The average slippage is 20 months behind original schedule.

To counter this and improve productivity

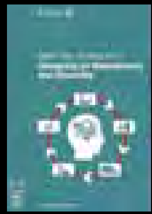
- Think modular design and standardisation
- Use prefabrication and pre-assembly methods
- Build only what is needed (design to value)
- Maintain a life-cycle perspective
- Strengthen scenario planning
- Optimise around site constraints
- Optimise engineering processes and choices
- Focus on quality
- Minimise waste.

Joshua Southern, *Smart construction: How offsite manufacturing can transform our industry* (London: KPMG, 2016).

KPMG's independent report evidences that off-site construction offers an alternative to the construction status quo by promising transformative improvements across the asset life cycle in time, cost, quality and health and safety. But most importantly, off-site construction offers predictability

Kate Harper, *Advanced Product Quality Planning: A Quality Oriented Approach to Construction* (unpublished draft, Manufacturing Technology Centre, 2017).

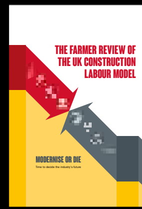
- Standardisation and introduction of industry quality standards have been critical success factors in automotive, aerospace, defence and medical appliance sectors, significantly reducing cost, timing and improving quality and competitiveness.
- Standardisation and quality should similarly be given centre stage in the construction sector.
- To achieve this there needs to be industry recognition of the need to change – and a desire to change.
- The construction sector needs to mobilise itself via an action group to create an industry quality standard.
- The introduction of a quality standard will facilitate component standardisation, promote collaboration and ensure common planning and procurement practices.



RIBA Plan of Work 2013 *Designing for Manufacture and Assembly* (London: RIBA, 2013).

The adoption of DfMA methods was found to achieve:

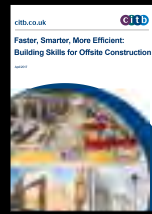
- 20%-60% reduction in construction programme time
- Greater programme certainty
- 20%-40% reduction in construction costs
- 70%+ reduction in onsite labour, with subsequent improvements in health and safety
- Reduced need for skilled labour on site
- Better construction quality
- Better environmental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



Mark Farmer, *The Farmer Review of the UK Construction Labour Model* (London: Construction Leadership Council, 2016).

'Critical symptoms of failure and poor performance' in the industry include:

- Low productivity
- Low predictability
- A lack of collaboration and improvement culture
- A lack of R+D and investment in innovation



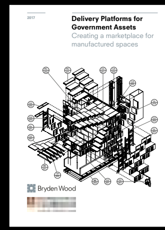
Faster, Smarter, More Efficient: Building Skills for Offsite Construction (London: Construction Industry Training Board, 2017).

- The ambition to grow and upscale the adoption of an offsite approach is underpinned by drivers including:
  - Skills shortages in the construction sector and capacity of offsite to address issues faced in the sector, notably low productivity and inefficiency;
  - The 'digitalisation' of the construction sector;
  - Emerging new technologies and a focus on 'smart' construction and greater automation in the future.
- Offsite construction offers economies of scale for the healthcare, hospitality, retail, leisure and education sectors.
- Future opportunities for upscaling offsite may come from the likes of large-scale infrastructure projects.
- Offsite construction may be more appealing as a career option for new entrants to the construction sector.
- Most existing training doesn't cover specific offsite skills because of its generic nature.

Construction Skills Network, Industry Insights: Forecasts 2017-2021 (London: Construction Industry Training Board, 2017).

- The construction industry continues to experience short-term skills issues and growing skills needs in the medium term.
- Well-planned and properly funded training programmes are crucial to the continuing success of our sector.

The progression of platform thinking



Jaimie Johnston, *Delivery Platforms for Government Assets: Creating a marketplace for manufactured spaces* (London: Bryden Wood, 2017).

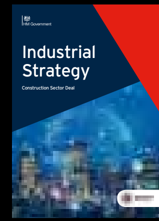
This document was written to inform the thinking around the development of a platforms approach, and was a precursor to the reviews and policies that followed.

2017
HM Government Autumn Statement backs MMC.

"The government will use its purchasing power to drive adoption of modern methods of construction..."

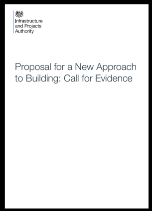
Infrastructure and Projects Authority, *Transforming Infrastructure Performance* (London: IPA, 2017)

One of three key challenges this document responds to is 'improving productivity in delivery'. The authors cite the Construction Leadership Council and suggest that 'significant gains could be achieved through the adoption of digital and manufacturing technologies'.



Industrial Strategy: Construction Sector Deal (London: HM Government, 2018).

An ambitious partnership between the industry and the government that aims to transform the sector's productivity through innovative technologies and a more highly skilled workforce. Focussing on digital technologies, manufacturing technologies and whole-life asset performance to deliver better-performing buildings, lower energy use, better jobs, better value for taxpayers and a globally competitive sector.



Proposal for a New Approach to Building: Call for Evidence (London: IPA, 2018).

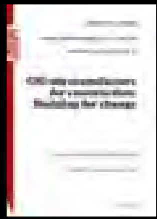
"A platform approach to DfMA means that we will use a set of digitally designed components across multiple types of built asset and apply those components wherever possible, thereby minimising the need to design bespoke components for different types of asset. For example, a single component could be used as part of a school, hospital, prison building or station..."

CONSTRUCTION INNOVATION HUB

<u>2018</u>
Formation of the Construction Innovation Hub.

£72 million government funding for a partnership between the Manufacturing Technology Centre, the University of Cambridge Centre for Digital Built Britain and the Building Research Establishment, to deliver the £72m Construction Innovation Hub (CIH), led by Keith Waller.

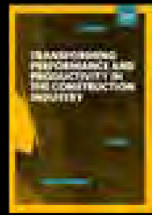
The funding followed a nationwide competition as part of the Industrial Strategy Challenge Fund.



House of Lords Science and Technology Select Committee, *Off-site manufacture for construction: Building for change*, 2nd report of session 2017-19, July 2018.

Off-site manufacturing for construction provides clear and tangible benefits which make a compelling case for its widespread use, yet still require:

- Government to work with the sector to equip the next generation of construction workers with new skills;
- Resources and leadership to be better integrated;
- Holding projects to account when they fail to explain why offsite was not used;
- Fostering an understanding of the R&D tax credits system.



Manufacturing Technology Centre, *Transforming Performance and Productivity in the Construction Industry* (London: MTC, 2019).

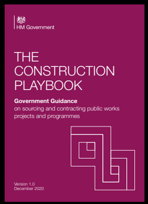
Outlines 'a suite of tools and systems that were used on a major project in collaboration with the Ministry of Justice, Bryden Wood and their delivery partners that were adapted from the manufacturing sector, where they have been proven to deliver step change improvement. These can be applied to the construction sector to help address government set challenges of improving productivity, build delivery and cost and time performance'.

The Forge, the world's first platform building, designed by Bryden Wood for Landsec, London.

Landsec, Easi-Space and Bryden Wood led a collaborative project to develop and test automated construction on a major commercial site in central London. Against Landsec's typical benchmarks, the project is targeting reductions in capital cost and programme time and a predicted 19.4% reduction in embodied carbon compared with traditional construction. It is designed to be the United Kingdom's first net-zero commercial building and, with automated construction processes and a multi-skilled workforce on the install, will result in a 13.5% productivity gain.

<u>2019</u>
Seismic school configuration app, designed by Bryden Wood, funded and launched by Innovate UK.

A groundbreaking project funded by Innovate UK led to the creation of a user-friendly, free and open-source web-based tool that accelerates – from weeks to minutes – the initial design and feasibility stages for new primary schools. It enables users to configure a primary school building that will exactly meet their user needs on a specific site, in full compliance with the Department for Education and all regulatory requirements. The app also democratises the process by including stakeholders in the process.



The Construction Playbook: Government guidance on sourcing and contracting public works projects and programmes (London: Cabinet Office, 2020).

Sets out 14 key policies amongst which are to develop a clear definition of the business needs, value drivers and desired outcomes; look to portfolios and longer term contracting; harmonise, digitise and rationalise demand; involve supply chain early; and develop an outcome-based approach.

Platform Design Programme: Defining the Need (London: Construction Innovation Hub, 2020).

Findings from the Construction Innovation Hub's analysis of a £50 billion, five-year, new-build pipeline by the Department for Education; Department of Health and Social Care; Ministry of Defence; Ministry of Housing, Communities and Local Government and Ministry of Justice estimate:

- £35 billion could be delivered with a defined range of mid-span platform systems;
- More than 50% of the space types across the pipeline are not department specific.

Delivery Platforms for Government Assets: Creating a marketplace for manufactured spaces

A version of this book was produced in 2017 by Bryden Wood Technology Limited with input from the Manufacturing Technology Centre, the Ministry of Justice, the Education & Skills Funding Agency and the Infrastructure and Projects Authority.

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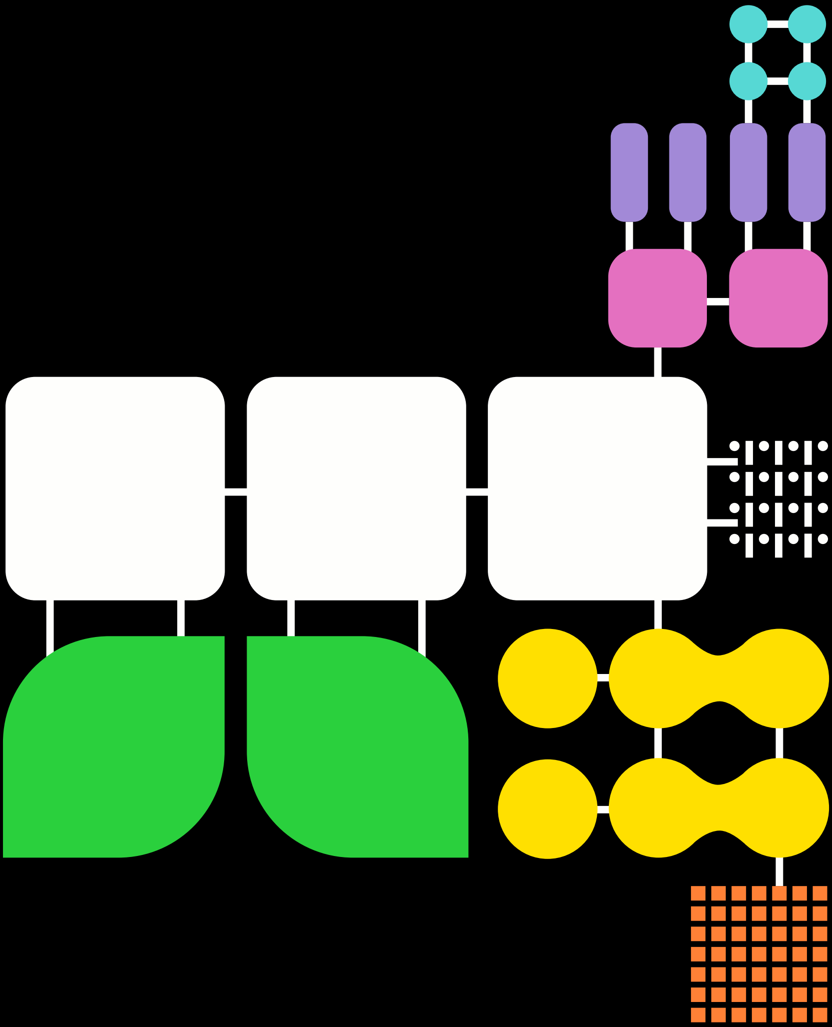

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